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PUMPS

THEIR

PRINCIPLES AND CONSTRUCTION.

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A SERIES OF LECTURES
DELIVERED AT
THE REGENT STREET POLYTECHNIC

BY

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AUTHOR OF "PLUMBING PRACTICE," "LECTURES TO PLUMBERS," "CLARKE'S TABLES," ETC.

WITH SEVENTY-THREE ILLUSTRATIONS.

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PREFACE.

THERE are already several books on Pumps, but most of them are so advanced in their treatment of the subject as to be above the ordinary workman or student, and none of them give the elementary information he requires, neither are the small details of construction entered into in them.

The subject matter of this little volume comprises a series of Lectures on the subject delivered to students at the Regent Street Polytechnic, and afterwards published in the pages of *The Plumber and Decorator*.

For presentation in book form they have been carefully revised and corrected, and it is hoped they will meet the need of those who require theoretical and practical information of an elementary nature on the subject.

The Author trusts that this may meet the same kind reception that has been accorded his previous publications.

J. WRIGHT CLARKE.

THE REGENT STREET POLYTECHNIC,
LONDON, W.

April, 1898.

LIST OF ILLUSTRATIONS.

PUMPS.

PUMPS that are in everyday use will be taken as our first subject. The common leaden "jack pump" is much used, and we will describe its parts and construction. Fig. 1 is a section in which G is the "suction" pipe, or the pipe that extends from the pump to below the water surface in the well or underground reservoir. H is the tail valve or "sucker," as it is usually called, made of elm. An enlarged sectional drawing of this is shown in Fig. 5. In the latter figure, I is a lead "clack," generally cast by the plumber in a "clack mould," with a "tang" for passing through the piece of leather, J, and rivetted on the other side and nailed to the sucker at K. In Fig. 1, L is the pump barrel, sometimes made out of a very strong piece of lead pipe, although a great many are cast in moulds. In some parts of the country plumbers make the barrels themselves out of plate lead, $\frac{3}{8}$ in. to $\frac{1}{2}$ in. thick, and "ladle burn" a seam on the side, as was described in my book "Plumbing Practice." The head, M, is only used on cast lead pumps. When the plumber makes the barrel himself it is usual for him to make it long enough above the nozzle N, to answer the purpose of the head and prevent the water overflowing the top when the nozzle does not take it away quickly enough. The "bucket" O is made of elm, and an enlarged section is shown by Fig. 2. A piece of leather, P, is nailed on near the bottom end. This is sometimes called the "bucket leather" and sometimes the "cup-leather."

Inside the latter is fixed another clack and leather as was described for the sucker. The bucket is fastened onto the rod Q, made of wrought iron and having a flange, R, upon it,

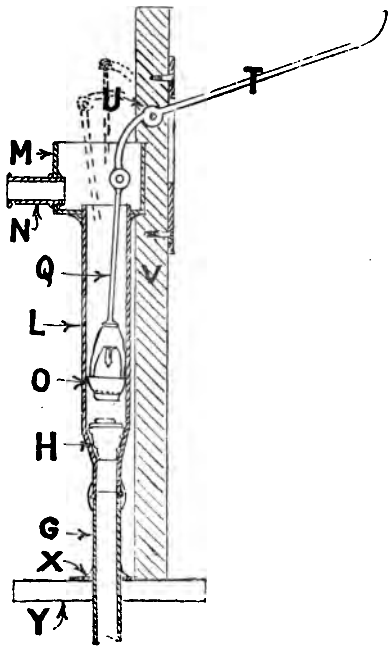

FIG. 1.

by means of a "split-key," S, and an iron washer to prevent the key cutting into the wood. The pump handle, T, Fig. 1, is made of wrought, although a great many are now used made of malleable-cast, iron. The handle works on a pivot or "pin," U, in the wooden plank V, which is mounted on a piece of oak, fixed over or at one side of the well, with bracing pieces to keep it steady and prevent rocking. The pin U is sometimes fixed by a

screw, through a flattened head which projects through the side of the wood plank.

Fig. 3 shows this pin and also the evil result of fixing it. By frequent usage the part at W is worn away, and an equal amount of friction in the hole or eye through the handle results in the latter also being much worn. If the pin is not fixed it revolves by the action of the handle, and in this case the hole through the plank wears away instead of the bolt. To prevent either of these evils the hole in the plank should be made large enough, and brass or gun-metal "bushes" inserted for the pin to

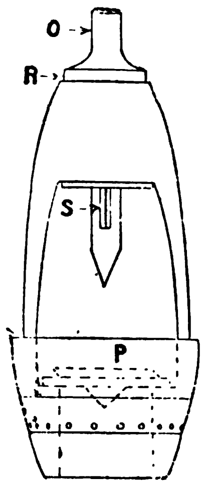

FIG. 2.

work in, the latter being free to revolve, and having a capping piece fixed over the end to prevent it working out of the plank.

In Fig. 1, it will be noticed that the pump head is notched into the plank. This should always be done, or other means taken, to prevent an up and down motion in unison with the handle when being worked. Neglect of this

precaution results in the suction pipe becoming detached from the pump, or in such a leakage, by which air can enter and prevent a vacuum being formed, that no water will be raised. If water refuses to come when the pump is worked, although the distance is not too far, the plumber's first suspicion is generally that there is a hole in the suction. To find if this is so the

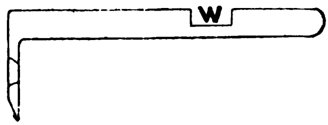

FIG. 3.

handle should be worked for a few minutes and then the ear placed close to, or touching, the nozzle. If a slight " sissing " noise is heard it will generally be found that the plumber's suspicions were correct, and there is either a hole in the pipe or the latter is cracked.

Another cause of the suction pipe leaking is careless or improper fixing, so that the whole weight is hanging onto the pump. A flange soldered on as shown at X, Fig. 1, helps to support the weight of both the suction pipe and pump, the base Y being either a piece of oak plank, or a stone slab, perforated for the pipe to pass through. Where the vertical length of pipe is several feet similar planks extending across the well, or perforated stone corbels built into the steining should be fixed, and lead flanges soldered on similar to that shown at X.

As a further support some plumbers will insert a wooden plug in the bottom end of the suction and nail on a piece of board, as shown by Fig. 4, to rest on the bottom of the well. This also helps to keep the pipe from stretching and sinking into the mud, which would be carried up and clog the sucker and bucket clacks. When the well is sunk in sandy or other loose soil the perforations, Z, should be kept up some distance from the bottom. When the pump is

to be used for sewage and similar liquids it then becomes necessary to have a strainer, as shown by dotted lines, or fix the pipe in a second chamber into which the liquid matter only is allowed to flow or pass. There are several details in putting a pump together ready for fixing that require consideration, and we will now dwell upon them. It is very rarely indeed that the soldered joint to the tail is properly socketted. Fig. 5 shows how it

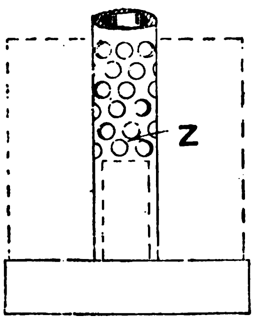

FIG. 4.

should be done. It will be noticed that the suction has a male, and the tail piece a female, end. Whenever it is necessary to repair or renew the sucker the rod shown by Fig. 6 has to be used. The end has a screwed point which is forced into the lead clack for pulling the latter off the sucker. Or an iron wire with bent end is passed down the barrel, the bent end worked under the edge of the clack leather, and the latter held open until the sucker rod has been passed through and the harpoon end placed under the bottom edge ready for dragging it out. Should the rod be lowered too far, and the soldered joint socketted the opposite way to that shown in the figure, the harpoon end would catch on the edge of the lead pipe, and the latter would be injured and torn. With the joint as shown in the figure this cannot occur.

To fix the sucker hard hemp, in distinction to soft tow, is wound round the outside and melted tallow poured out of a ladle onto it, the whole being held on the point of the sucker rod, which is screwed into the lead clack just sufficient to hold it, and then lowered into its position in the pump. The rod is then unscrewed, taken out, reversed, and the sucker driven down by

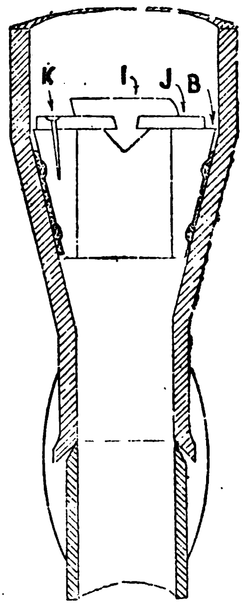

FIG. 5.

the flat head, A, Fig. 6. When taking the sucker out for repairs some plumbers will first pour boiling water into the pump, others will burn straw or paper, or surround with hot water rags, on the outside of the pump tail. This remelts the tallow, and also slightly expands the lead, so that lesser force has to be used to get the sucker out.

The hemp should be wound on very tight, and be not less than half-an-inch from the top edge. If loosely done, too much used, or too high up, some portion will project above the sucker, get beneath the clack leather, and prevent its closing properly. The leather should not be too large, and it is an advantage to allow for a probable stretching, otherwise it will rub against the side of the barrel. A clear space should be left, as shown at B, Fig. 5.

The bucket should be well soaked for an hour or two in water before using, otherwise it will split when nailing on either the outside or the clack leather. The leather is generally of the kind used for boot soles, and called "water-dressed," although some plumbers prefer "oil-dressed" for lead jack pumps. A strip about ½ in. longer than the girth of the bucket, and from 1½ in. to 2 in. wide, according to the size of the pump, is well soaked in water and then the ends and one edge chamfered on the rough side. It is then nailed onto the bucket, as shown at P, Fig. 2, small copper nails being used, and care taken that the bottom edge does not project above, but is even with, the groove cut in the wood. The clack should be fixed before the cup leather is nailed on and freedom at the edges allowed for, as described for the sucker clack.

The buckets are generally bought, although some country plumbers who have lathes will turn them themselves, and have a small hole through them for fixing on the rod. To enlarge this to the exact size the end of the rod is made red hot and forced through the hole through which it burns its way. This should be done very quickly and the whole immediately plunged into water, otherwise the hole would be burnt too large, and the bucket could not be firmly fixed on the rod. Iron washers and a "split key," as shown at S, Fig. 2, are used for the latter purpose.

Great care has to be taken in mounting the bucket rod and pump handle. If the pin in the plank is too high up, so much water is not

raised, owing to the shortness of the stroke, and the bucket is drawn partly out of the top of the barrel. If the pin is too low down the bottom of the bucket knocks on the top of the sucker at each upward stroke of the handle.

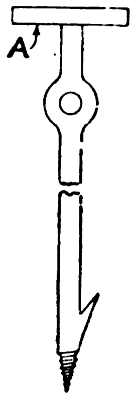

FIG. 6.

Another evil in the latter case is the bending of the bucket rod, or the wearing and distorting of the inside of the top of the pump barrel by the rocking to and fro, as shown by dotted lines, Fig. 1, at each up and down stroke of the handle.

When preparing a square cast lead head for soldering on the barrel and nozzle, the holes are best made by burning, or melting, through with a red hot plumbers' iron. This does not distort the lead so much as when they are cut with a chipping knife and hammer. With a cast lead pump the end of the nozzle is soldered on the inside of the head, and as near the bottom as possible. The barrel joint being wiped on the outside. The end of the barrel should project about ½ in. to ¾ in. above the bottom of the head, and thus lessen the risk of anything falling in and getting jambed between the bucket and sides. All jack pumps with open tops should

be encased with woodwork to prevent anything falling in and injuring any parts. No doubt many readers can recall similar experiences to the writer's, where mischievous children have stood at a distance and pitched pebbles into the nozzle, and can realise the difficulty of getting them out again, especially after an attempt has been made to work the pump.

The diameter of the suction pipe is usually considered as half that of the barrel. That is a 4 in. pump should have a 2 in. suction, and a 3 in. pump an 1½ in. suction. These sizes have become established by practice. We will deal with this matter and the principles of the action of a pump before describing any other kinds.

To thoroughly understand the action of a pump it will be necessary to first explain what "atmospheric pressure" means, as this influence has a great deal to do with the subject. When reading the weather reports, as published in newspapers, we find the statement "Barometer 30·0 in. over the Spanish Peninsula; 29·9 in. in Sweden; 29·78in. at Brixton;" and so on for other parts of the world or our own country, the figures varying from day to day and almost hour by hour. Accompanying these reports is a paragraph stating "The barometrical readings are corrected to sea level, and reduced to 32 degs. Fahr."

The atmosphere surrounding our earth presses, we may say almost like water, in all directions. As we leave the earth and get higher up into the air, as when mountain climbing or ballooning, the pressure is reduced, and as we go down, into a mine for instance, it is increased. The height of mountains, or balloons when soaring, can be found by the use of a barometric tube. As the air is of different densities at different heights, for the purpose of making calculations it is necessary that some datum should be fixed to work from. As we live on the surface of the earth it is found to be convenient to have some level as near as possible to that in which we live and this, fixed upon by scientists, is the "sea level." Heat has an influence on atmospheric pressure. Heated air is expanded

air. A cubic foot at 32 degs. Fahr. weighs ·0807 lbs., at 22 degs. ·0824 lbs., and at 42 degs. ·0791 lbs. Hence the necessity of taking note of the temperature when making calculations as to atmospheric pressure. The datum for this is 32 degs. Fahr. Old pump hands no doubt have noticed that on some days a pump fixed just within the limits will deliver a fair amount of water and on other days will not deliver any. This has arisen from the variations in temperature and atmospheric pressure.

A barometer is an instrument by which we measure the air pressure, and consists of a tube having one end sealed and made air-tight, and the other end bent upwards as Fig. 7. The length of the longest part being about 36 in., and the short one 4 in. This tube is filled with mercury, care being taken to get out all the air otherwise it will not act properly. When filled and stood upright, as shown in the figure, an empty space, or vacuum, will be left at the top, B, and some portion of the mercury overflow the short end C. A further small quantity being emptied out and a float placed in the end with a thin cord attached and passed over a pulley wheel, D, with a small counterbalance weight at E, the whole constitutes an ordinary barometer. The dial or pointer moves round as the air pressure varies and the mercury is pushed up into the vacuum at B. The instrument is sometimes called a "weather glass" and the face, or dial plate, which is not shown in the figure, is marked with terms denoting the state of the weather. But it is only a weigher of the density of the air. As variations in the latter usually precede a change in the state of the weather the barometer is a valuable aid to foretelling what form those changes will take.

If the measured distance between the exposed surface of the mercury in the short leg and that in the vacuum end of the tube is 30 in. we then say the barometer reads that pressure.

Anyone can make an instrument for demonstrating atmospheric pressure. Buy a strong glass tube with about ⅛ in. bore and 34 in. long and seal one end by the aid of a flame and blow-

pipe. Also buy a small glass jar, about the size of those supplied with cheap bird cages, and one to two pounds of mercury. Stand the tube on its closed end, in a basin or saucer to catch spilled mercury, and fill quite full. Pour the remainder of the mercury into the glass cup or jar, place a finger over the open end of the filled tube, invert it and plunge it into the jar. On removing the finger some of the mercury will pass out of the tube and leave a vacuum in the top. On measuring, it will generally be found that the distance between the surfaces of the mercury in the vacuum and open jar will be 30 inches.

We can now place an india-rubber bung, with a hole through it, on the tube, and lower the jar and immersed end of the tube into a wide-mouthed bottle, as shown by Fig. 8. Through a second hole in the bung pass a piece of glass tube having a stop-cock, or a piece of india-rubber tubing with a brass spring clip instead of the cock. If the bung fits quite air-tight, and a person blows through the small tube into the bottle, the atmospheric pressure inside will be increa-ed, and some of the mercury will be forced up the tube into the empty space at the top end. If, on the contrary, some of the air is sucked out of the bottle, the pressure will be reduced, more mercury will run into the cup and the vacuum space at the top end of the tube increased. Blowing into the tube has the same effect as if the apparatus had been lowered down a deep mine or some position considerably below the level of the sea. Exhausting the air produces the same result as if the tube, &c., had been carried up a high mountain. From this we find that, measured from our usual datum, the pressure of the air will support a column of mercury, in a vacuum, to a height of 30 in.

If the pressure of the atmosphere is taken at sea level, the temperature as before stated, and we find it will support a column of mercury at the above height, we then know that the air pressure is equal to 14·7 lbs. on the square inch. To find this we multiply the weight of 1 cubic

inch of mercury, ·4903 lbs., by the height of the column in the vacuum tube, which is 30 in., or $\cdot 4903 \times 30 = 14 \cdot 7090$, or 14·7 lbs. in round numbers.

If we were to take a tube about 35 ft. or 36 ft. long, seal one end, as we did with the mercury tube, lay it in a long trough of water and slightly

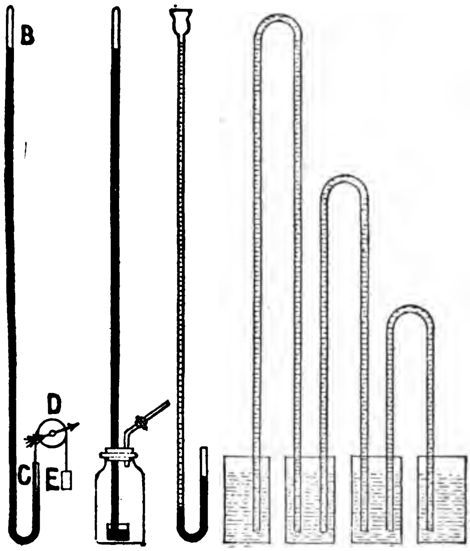

FIG. 7. FIG. 8. FIG. 9. FIG. 10.

raise the open end for the air to escape and water to take its place, and then stand the pipe upright without taking the open end out of the water we should find that a vacuum would be left at the top similar to the one in the mercury tube. But in this case, roughly speaking, the measurements would be in feet instead of inches. This is a difficult experiment to use in a class-room owing to the unwieldy length of the tube. But we can continue our illustrations and show by another small tube the relative weights of mercury and water.

Take a piece of ¼ in. or ⅜ in. glass tube about 5 ft. or 4 ft. long and bend one end, about 5 in. or 6 in., as shown by Fig. 9, and stand on the bent end. Pour mercury into the tube to a height of about 3 in. It will be this height on both sides of the bend as the ends are open and the air can escape as the mercury is poured in. Now pour water into the long leg until it is filled or nearly so. On looking at the mercury we find it has risen in the short leg and lowered on the opposite side, as shown by the dark part in the figure, and by measurement we find the difference in height is about 3 in. I said about, because it is difficult to take an exact measurement owing to the refraction of the glass and the surfaces of the mercury not being even, but raised, or convex, in the centre. To find if the 3 in. is correct, we can measure the height of the column of water above the mercury and divide by the specific gravity, or relative weight of the latter when compared with that of the former, which is 13·596, or say 13·6, at a temperature of about 60 degs. F. Assuming the water measures 3 ft. 4 in. in height. Then 3 ft. 4 in. or 40 in. ÷ 13·6 = 2·94 in. as being the exact difference in the level of the two columns of mercury in the bent tube.

Our experiments have shown :—

(*a*) Under ordinary conditions the atmospheric pressure will support a column of mercury in a vacuum at a height of 30 in.

(*b*) One inch of mercury exerts a pressure of 13·6 times that of an equal bulk of water, and

(*c*) The pressure of the atmosphere is equal to 14·7 lbs. on the square inch.

With this knowledge it is easy to calculate the depth from which a pump will raise water, and the rule is as follows :—

Divide the atmospheric pressure in lbs. per square inch by the weight of 1 square inch of water 1 ft. high. In a previous lecture we found the latter to be ·434 lb. Then 14.7 ÷ ·434 = 33·87 ft. or 33 ft. 10½ in. nearly.

This distance measured from the top of the valve in the pump bucket to the surface of the water in the well is the extreme limit. The

weight of water in the pipe and the atmospheric pressure on the outside water are in a state of equilibrium. In this state no water would be delivered by the pump. If the distance is measured from the sucker clack no useful work would be done as the water would not be pushed any higher than that level.

When pumping, it is found that the surface subsides as the water is drawn up, hence a pump may answer satisfactorily for a short time and then "give out," as it is called, although there may be plenty of water at a lower level. After an interval it will again do what is required and after using again give out. This is because the water surface exceeds the theoretical distance below the bucket. It is necessary to again remind the student that temperature and atmospheric pressure have to be considered, and that 1 in. of variation in a mercury barometer is equal to about 13½in. in a water barometer. To find the working height of a pump we add together the amounts we should allow for probable contingencies and have :—

	ft.	in.
Subsidence of water in the well, say	3	0
Variation in barometer = 1 in. ...	1	1½
Length of bucket stroke		9
Which gives a total of ...	4	10½

and this must be deducted from the 33ft. 10½in., which leaves 29ft. On no account should a pump be fixed with its bucket more than the latter distance above the water it is to raise. In everyday practice it is as well to reduce the distance to 25 ft. or less.

The above distance can be varied for hot and sea waters, the former being lighter and the latter heavier than ordinary or spring. If spring water at 62 degs. Fahr. weighs 62·32 lbs. per cubic foot, at 212 degs., or boiling point, it weighs only 59·82 lbs. By working this out as in previous problems, we find that the theoretical height to which boiling water will be pushed when the mercury barometer stands at 30 in. is nearly 34 ft. as against 33 ft. 10½ in. with the cold water. But here another detail has to be

considered. Water boils at 212 degs. in an open vessel, when it may be said to be under a pressure of one atmosphere. If this pressure is reduced the boiling point is at a much lower temperature. Water heated in a flask or vessel to 180 degs., and then placed under the receiver of an air pump will boil violently, and large quantities of steam be given off when the pressure has been reduced to half an atmosphere. Even with a defective air pump, the writer has found water to boil as low as 120 degs. Water in a suction pipe of a pump will boil at a very low temperature and give off large volumes of steam. This interferes very much with the quantity of hot water raised by a pump.

If we take the specific gravity of sea water as 1·027 by calculation we find that a cubic foot weighs 63·98 lbs. If we divide this by 144 we have ·4443 lb. as the pressure on a square inch for one foot in height. And $14·7 \div ·4443 = 33·08$ or say 33 ft., this being the theoretical height to which sea water of ordinary density would rise, in the suction pipe of a pump, above the level of the water surface.

We now know the limit from which water can be raised by a pump to its own height.

It may here be considered convenient to refer to the action and limits of a syphon. If a tube is bent to the form of a ∩ it will form what is commonly known as a syphon. If filled with, and one end placed in a vessel containing, water, the contents of the vessel will run out of the outer tube until the inner end is exposed so that air can enter, always provided that the outside leg was the longer of the two. If the bent tube was filled and then the two ends dipped into cups or other vessels, as shown by Fig. 10, the contents of the latter would stand at the same level, and if water was dipped out of one and poured into the other, it would at once run back until the levels were again the same. And this would act with tubes of any size and any length within the limits that have been explained in connection with a pump suction. A row of water vessels all connected by means of

syphons which were charged would remain filled to the same level, provided they all stood on the same horizontal line. If one vessel is raised or lowered, the contents will be syphoned out in the former case and increased in the latter. To test this with a water syphon to a height of 33 ft. 10½ in. would be a troublesome matter, and would require an arrangement of stop cocks for filling and starting, but here again we can make use of mercury. If the arrangements shown by Fig. 10 were charged with mercury the same results would obtain as with water, if the length of the tubes was less than 30 in., measured from the surface of the contents of the vessels. But if this height was increased only 1 in., or if the atmospheric pressure, as registered by a barometer, was 29 in., the syphon would cease to act and, if made of glass, an empty space, or vacuum, would be seen at the top. We thus find that pumps and syphons are bounded by equal limits as to the height at which useful duty can be performed.

In previous remarks the word "push" has been made use of, and it now becomes necessary to explain the meaning or application of that term. With junior students there is an impression that the water in a pump suction is dragged or lifted up when the handle is worked much in the same manner as if the water was a solid body, or had sufficient tenacity to resist being pulled asunder. Water does cling together it is true, but the cohesion is so very low that there is little or no difficulty in separating portions of it. When the handle is first worked the bucket is perhaps several feet away and is not in contact with the water in any way. When a pump is first fixed there is air inside it and also in the suction pipe. This air exerts, as we have already found, a pressure of 14·7 lbs. on each square inch of surface exposed to it. And this amount of pressure is exerted on the surface of the water inside the pipe as well as on that outside or, as we usually express it, the pressures are in a state of equilibrium. When the pump handle is raised and then

lowered the bucket first descends and then ascends. When ascending it lifts up the air pressing on its upper side, and in doing this takes off that on the water inside the suction pipe. The internal and external pressure being unequal, that outside, on the surface of the water in the well, being the greater pushes the water up into that part where the atmosphere is no longer exerting any pressure. After the first stroke, when some of the air has been exhausted out of the suction, the remainder being no longer pressed closely together by the weight above it, expands and becomes less dense. The handle being again worked more air is lifted out, the remainder is more rarefied, and, by repeating the operation, becomes so thin as to approach what is generally termed a vacuum in the containing space. External air presses or pushes the well water into this space, and the working of the bucket then lifts some of the water out leaving a vacuum behind which is again filled as before. The water above the bucket is lifted out, but that below is pushed up as above stated.

And so with a syphon. But in this case the tube has to be first filled with water before placing in position, or the air has to be drawn out by some means until none is left, after placing in position. When charged, the water in the outside, or long leg, is heaviest and falls down, and more is pushed up the inner leg by the atmospheric pressure on the surface of that in the vessel. And this goes on so long as any remains or until the inner end is exposed and air can pass in. To restart the syphon this air must again be exhausted.

To work a pump a certain amount of force or power must be exerted. With a jack pump the appliance is a lever, or as we call it, the handle. The advantage of this mechanical appliance can be explained by studying a pair of beam scales, as shown by Fig. 11. Assuming that the scales are exactly balanced and are hung on the extremities of the arms the same distance from the pillar, or fulcrum, a weight of ten or any number of pounds placed in one pan would

balance an equal weight placed in the other side. But in this case there is no gain of power. Ten pounds of applied power only produces ten pounds of work done by lifting, as the power and work are balanced and the two move through the same distance or space in the same time. If we were to move the pillar nearer to one of the pans and assume that they were both adjusted so as to still balance each other, then a large weight in one pan would be necessary to raise a small one in the other. And on the con-

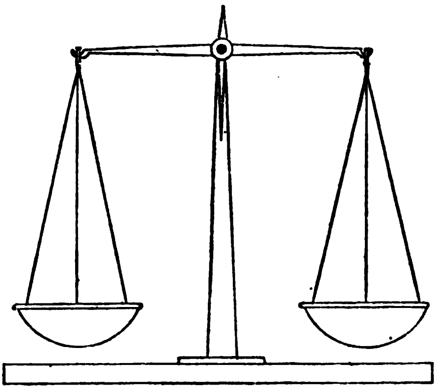

FIG. 11.

trary, a small weight at the long end of a lever would support a heavier weight at the short end. Assuming that Fig. 12 is a balanced lever supported on a centre or fulcrum at F. W is a weight to be lifted, and P is the weight or power to be applied to lift W.

The formula for working this is

$$P = \frac{W \times S}{L}$$

W being the weight.
S the length of the short arm.
L the length of the long arm.
And P = the power to be exerted.

W = 100 lbs.
S = 6 inches
L = 30 inches

Then $P = \frac{100 \times 6}{30} = 20$ lbs. which would just balance W.

Or if we take another example to find the length of the long arm and

$$W = 500 \text{ lbs.}$$
$$S = 12 \text{ inches}$$
$$P = 40 \text{ lbs.}$$

The formula becomes

$$L = \frac{W \times S}{P} \quad \text{or}$$

$$L = \frac{500 \times 12}{40} = 150 \text{ in.}$$

The length of the long arm to balance W.

In the case of a jack pump the power is derived from the man who works the lever or handle. As the man exerts his power at arm's length he cannot do so much work as if the lever was placed in a more favourable position, or where he could stand over and push and pull with least fatigue to himself. When using an

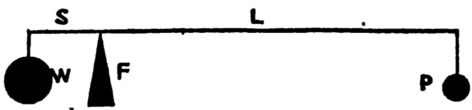

FIG. 12.

ordinary pump the man has to first raise the handle, and, if the latter is properly balanced, this does not require much exertion. But when pulling it down he must use sufficient force to raise the load hanging onto the bucket at the other end. For continuous work at arm's length an average man cannot pull down with a power exceeding about 20 lbs. of weight, and we may take this as a basis for calculations. In our lever problems this would be looked upon as a constant P.

We will now deal with the weight to be raised, that is, the column of water on and under the bucket. The rule for this is :—Diameter of the cross section of the pump barrel squared × the distance from the surface of the water in the well to the surface of that in the pump × ·34.

Assuming a 3 in. pump and 20 ft. as the height of the column of water.

Then $3^2 \times \cdot 34$ lb. $\times$ 20 ft. = 61 1-5th lbs. In this rule ·34 lb. is the weight of water contained in 1 ft. of 1 in. pipe, and is found by dividing 62·5 lbs. by 144 in. and $\times$ ·7854. If the length of the bucket end of the handle is 6 in. long, measured from the centre of the plank pin to the centre of the bolt of the bucket rod, we can then find the length of the handle necessary for a man to use the pump with useful effect.

Then, using the same formula as for the lever :—

$$\frac{61 \text{ lbs.} \times 6 \text{ in.}}{20} = \frac{366}{20} = 18\tfrac{1}{4} \text{ in.}$$

This length would not allow space for the man to grip with both hands at the extreme end of the handle, and in addition there would be no preponderance of power over load. To make an allowance for this at least 6 in. should be added onto the length of the handle, thus making it 24 in. long.

We may take another example with 25 ft. length of column and a 4 in. pump. Then $4^2 \times \cdot 34$ lbs. $\times$ 25 ft. = 136 lbs. to be lifted. If the length of the short arm is 7 in. we then have

$$\frac{136 \times 7}{20} = \frac{952}{20} = 47\cdot 6 \text{ in.}$$

as net length of handle to which should be added 6 in. for reasons above given.

The total length of about 4 ft. 6 in. would make the handle unwieldy and difficult for a man of ordinary stature to work. Neither could he reach high enough to get the full length of stroke, which should be about 12 in. in the barrel of the pump. To do this his hands would have to travel a distance of over 7 ft. If the handle was 3 ft. long his hands would pass through 5 ft. 5 in. of space, and if 2 ft. 6 in. long, the distance would be 4 ft. 5 in.

Fig. 13 is drawn to scale to more clearly explain this. To work the 4 in. pump and get the full effect a shorter handle should be fixed and two men employed if for continuous work.

One man would perhaps be able to get uselul effect, but for a short time only.

In these calculations we have assumed that the handle just balanced the short arm and the

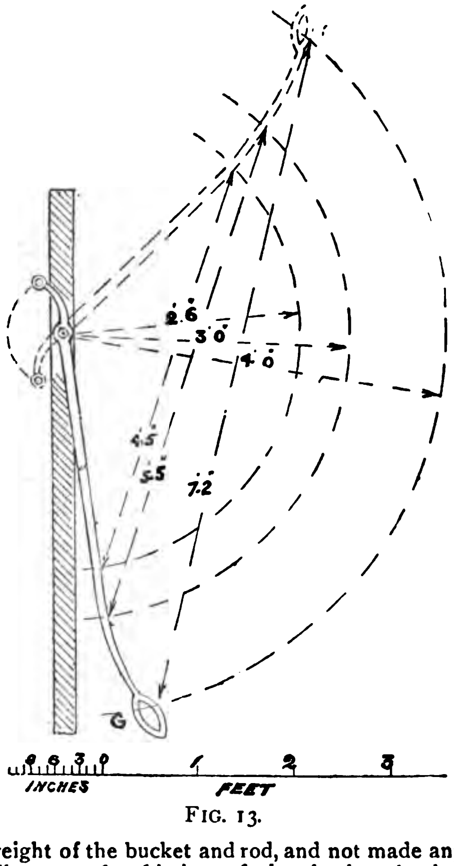

FIG. 13.

weight of the bucket and rod, and not made any allowance for friction of the bucket leather against the inside of the barrel. This should be done. When the bucket is going downwards

the friction is very small, but when rising it is considerable, as the leather is pushed or pressed closely to the sides of the pump. As *friction is proportional to load*, the greater the depth from which the water is being raised the greater the friction. No fixed rule can be given that would suit all conditions, but we may assume that two pounds on the end of the handle would be an average allowance to overcome the additional load in the form of friction.

Mention has been made that, when properly balanced, not much exertion is required to raise the handle. But if we were to make the latter heavier than the bucket and rod we should then have to exert more power when raising the handle, but less when pulling it down. Advantage can be taken of this to lighten the man's labour when pumping. Assuming that the end of the handle is swelled out to the form of a bulb at G, Fig. 13, and that this and the handle itself weighs ten pounds more than the weight of the bucket and rod. If we deduct from this the two pounds we allowed for the bucket friction we have eight pounds remaining, and this is equal to adding that amount of power to the man's arms when pulling down.

To show the advantage of this we will again take the problem of the 4 in. pump with the 25 ft. column of water.

Then $\frac{136 \times 7}{28} = 34$ in. as length of handle,

to which we may add a few inches for gripping as before. On referring to Fig. 13 it will be seen that the man's hands would travel a distance of about 5 ft. 5 in. Although we have gained in power we still find that the task is too heavy for one man to work at continuously for any length of time. We could still further reduce his labour by shortening the distance the bucket travels. This would be done by reducing the length of the short arm of the handle. Although his actual efforts would be less they would have to be sustained for a longer time if a given quantity of water has to be raised.

If the short arm was 6 in. long, instead of

7 in., we should then find, again using the last problem,

$$\frac{136 \times 6}{28} = \frac{204}{7} = 29 \text{ 1-7th in.}$$

as the net length, to which add 6 in. as before = 35 in. On referring to Fig. 688 it will be seen that the hands travel a distance of 4 ft. 5 in., which is a great saving on the preceding example.

It may have occurred to readers that the weight of water resting on the bucket and contained in the suction pipe has been assumed to be the same as the contents of a pipe equal in area to the full size of the barrel. In other words that the suction is the same diameter as the barrel. In practice, the diameter of the former is usually half that of the latter. In a 4 in. barrel and 2 in. suction the contents are as 4 is to 1. Consequently the water in one foot of the pump weighs four times as much as is contained in one foot of the pipe. But we are not dealing with weight of water, but with atmospheric pressure. When raising the bucket we raise the water which is above it, and also a column of air of the same diameter as the barrel. And the weight of this is equal to a column of water of equal diameter with the pump, assuming it is fixed within the proper limits or distance from the water in the well.

If the suction and pump are of equal diameters the latter will work easier, although there is a larger quantity of water in the former. By reducing the size of the pipe we make the work harder for the operator. It may here be stated that *friction increases as the square of the velocity.* If a 4 in. pump has a 12 in. stroke, is worked at the rate of 30 strokes per minute, and the up and down travel of the bucket take equal times, the water is then moving at the rate of one foot each alternate second. If the suction was of equal area to the barrel we should have the same velocity in both. But if we fix a smaller suction then the water in it must travel at a higher speed. With a 2 in. suction the speed would be four times that in

the 4 in. barrel. And the square of 4=16, or the number of times that the friction would be increased over what it would be if the pump was of the same diameter.

The writer has seen jack pumps fixed with suctions much too small. For instance, 3 in. with 1 in., and 4 in. with 1½ in. suctions. This is always a false economy, as, although there may be a slight saving in the first cost, extra effort is required to work such fittings, and wear and tear of the human frame should always be considered in our calculations. At all events, it is not necessary to waste strength on unproductive results. The diameter of the suction should never be less than half that of the barrel.

Inertia of water is another factor which should be considered in pump work. Like all inanimate bodies, water has no power in itself to move nor to stop when in motion. When pulling down a pump handle, the first part of

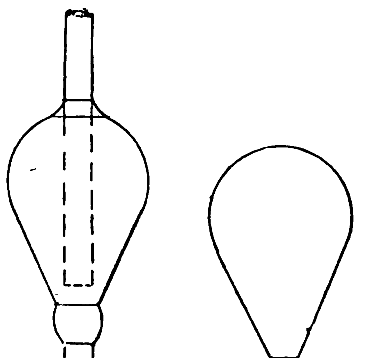

FIG. 14. FIG. 15.

the labour is expended in overcoming the inertia and putting the water in motion. The rest of the stroke, after movement has been started, being much easier. With ordinary jack pumps this extra effort is required at each

stroke. When the suction pipes are very short this does not much matter, but when they are very long it will economise labour if an air vessel is fixed, as shown by Fig. 14, when the pipe is vertical, or as Fig. 15 when horizontal.

To explain the advantages of air vessels, we must first remember that air is elastic and can be compressed into a smaller space or expanded to fill a larger one. In either case the air retains its physical or natural property of returning to its original density when opportunity offers. The air in a vessel attached to the suction pipe of a pump is rarefied or made thinner by the weight of water in the pipe beneath it, and which is drawn down in common with all bodies by the attraction of terrestial gravity—the opposite force being the pump bucket by which the air in the first instance and water afterwards is lifted out of the barrel as fast as it is pushed up from the well.

To make the action clear, we may try an experiment with a piece of flexible indiarubber or a spiral spring. If one end is fixed to a beam, or similar support, and a weight suspended from the other, the spring will elongate or stretch. A gentle pull given to the weighted end would still further stretch the spring, and on releasing the pull, the extra tension being removed, the weight would rise to its first position.

After starting the pump and exhausting the air out of the suction pipe, that in the vessel is stretched or expanded to a certain degree of rarefication, and remains so, although the pipe is full of water, until the handle is again operated when it is still further expanded. As soon as this extra tension is removed the air in the vessel begins to return to the same state it was before, and to do this water must rise in the suction pipe. During the time this is occurring the pump handle is being raised for the next stroke, so that when it is pulled down, the water in the suction being already in motion, so much effort is not required at the commencement of the downward stroke.

The best position for the vessel to be fixed in the suction pipe is as close to the tail valve of the pump as may be convenient.

The advantage of an air vessel is particularly noticeable where a pump is fixed a considerable distance from the well. The writer had a case a few years ago where a pump in a rose garden was used for raising liquid sewage from an underground tank distant about 100 yards. The vertical height to which it was raised being about 15 ft. An air vessel made the pump much easier to work. We have now dealt with (*a*) a jack pump and its parts and construction, (*b*) the power to work it, (*c*) how to calculate the length of the handle, (*d*) the size of suction pipe, and (*e*) the advantage of an air vessel when the suction is very long. We may now consider the useful effect to be got out of a jack pump.

The theoretical quantity of water raised in a given time is found by multiplying the squared diameter of the barrel in inches by the length of stroke by the rate or speed of working, and by ·034. Example, a 3 in. pump, with 9 in. stroke and 30 strokes per minute. How much water raised in one hour?

Then $3^2 \times {\cdot}034 \times {\cdot}75 \times 30 \times 60 = 413{\cdot}1$ gallons.

Worked as follows

$3^2 = 9$ in.		
$\times\ {\cdot}034$	=	Contents in gals. of 1 ft. of 1 in. pipe.
.306	=	Contents in gals. of 1 ft. of 3 in. pipe.
$\times\ {\cdot}75$	=	9 in. in decimal parts of 1 ft.
1530		
2142		
·22950	=	Contents in gals. of 9 in. of 3 in. pipe.
$\times$ 30		Number of strokes per minute.
6·88500		
60		Number of minutes in one hour.
413·10000	=	Gals. per hour the answer.

Another example with a 4 in. pump, 12 in. stroke and 20 strokes per minute.

Then $4^2 \times {\cdot}034 \times 1 \times 20 \times 60 = 652{\cdot}8$ gallons per hour.

The rule can be varied to find other factors

besides the quantity raised. As an example: Find the diameter of a pump to deliver 1,500 gallons per hour with a 12 in. stroke worked at 20 strokes per minute.

The rule arranged as a formula is

$$D = \sqrt{\frac{G}{C \times S \times M \times L}}$$

Where G = Gallons raised.
„ D = Diameter of the pump in inches.
„ C = Contents in gallons of 1 ft. of 1 in. pipe = ·034.
„ S = Strokes per minute.
„ M = Minutes per hour.
„ L = Length of stroke in feet.

Then

$$D = \sqrt{\frac{1500}{\cdot 034 \times 20 \times 60 \times 1}} = 6\cdot063 \text{ in.}$$

or say 6 in. the diameter required.

Or assuming that we want to find the length of stroke, other particulars being given.

Example: a 4 in. pump, 25 strokes per minute and 700 gallons raised per hour.

The simplest method is to first find what the pump would discharge with a 12 in. stroke.

Then $4^2 \times \cdot 034 \times 25 \times 60 \times 1 = 816$ gallons discharged with a 12 in. stroke.

And as 816 gals. : 12 in. : : 700 gals. : 10·294 in., which is the length of stroke for 700 gals.

In these calculations the length of stroke has been taken as representing the length of a column of water, of the same sectional area as the pump barrel, discharged at each completed motion of the handle. When the latter is raised part of the bucket rod and bucket, which was above the water line, is immersed and displaces some of the contents of the barrel causing them to flow out of the nozzle. On pulling down the handle the bucket rod is raised out of the water, and the quantity flowing out of the nozzle is not the full contents of the barrel but is minus the space which was occupied by the rod. But the completed up and down stroke raises the quantity which we found by our calculations.

We have now to consider the difference between theoretical and actual work done by a pump. The former we have already dealt with. To get the full effect the pump must (*a*) be in thorough order and condition, (*b*) worked at a certain spead, (*c*) the bucket should work concentrically with the barrel, and (*d*) fixed with due regard to the principles that have been laid down. Failing these conditions the results are below those arrived at in our calculations.

Dealing with (*a*). If the pump has holes in the suction pipe, air will be drawn in and less water delivered. If the bucket leather is much worn, or the inside of the barrel bruised, or roughened by corrosion, or if the clack leathers do not fit tight, less water would be delivered and an allowance for "slip" must be made in all calculations. (*b*) All pumps work best at certain speeds. If too fast or too slow the full effect is not attained, although slow speeds do less injury than the fast to the working parts. Pumps with long strokes, worked at moderate speeds, are more effective than those which are worked at a quick rate with short strokes. (*c*) A reference to Fig. 1 will show that with ordinary Jack-pumps the bucket does not work concentrically with the barrel, but rocks, so to speak, to and fro as it moves up and down. Two sides of the bucket, and corresponding inside portions of the barrel are subjected to excessive wear, and in this case, too, an allowance must be made for "slip." (*d*) When pumps are fixed too far from the well water, none at all is raised; but if just within the limit a lesser quantity is delivered than would be if the height were less. When the handle is not properly mounted, or if the bolt or its bearings, or the hole in the handle is much worn, the length of the stroke is shortened, and although the exertions of the man are nearly the same the results are below what they would be if all the arragements were perfect.

The allowance for "slip" has to be varied, according to circumstances, from ·025 per cent. for new pumps as the sucker clack is in the act of closing, to 30 or 40 for old ones.

Example : with a 2 in. pump, 8 in. stroke, 30 strokes a minute, slip, 10 per cent. How much water raised in half an hour ?

$$G = 2^2 \times \cdot034 \times \cdot66 \times 30 \times 30 = 80\cdot784$$

and 80·784—10 per cent. = 72·706 gals. actually delivered.

To vary the last example we may assume a cistern holds 500 gals., and it takes a man just one hour to fill it with a 4 in. pump having a 12 in. stroke and worked at the rate of 25 strokes per minute. What is the proportion of slip?

If the pump was in good order we should have $4^2 \times 1 \times \cdot034 \times 25 \times 60 = 816$ gals. as being the actual quantity which would have been raised. But as only 500 gals. are pumped into the cistern we have 816—500 = 316 gals. to allow for as having escaped past the bucket and sucker when pumping.

Then : As 816 : 100 : 316 : 38·725 the per centage of slip owing to the defective pump.

With regard to the strength of materials for pumps the lead suction pipes should not be less than those in the following table for good work.

Size of bore of pipe.	Weight in lbs. per yard lineal.	For pump whose diameter is
1 in.	12	2 in.
1½ in.	20	3 in.
2 in.	27	4 in.
3 in.	35	6 in.

The weights can be slightly reduced for cheap work. Those in the table average from about 1-5th in. thick for 1 in. pipe to ¼ in. for 3 in. pipe. Suction pipes do not have to resist a bursting pressure, that is, an internal force pressing outwards, but an external or outside force tending to crush the pipe. This pressure being exerted by the atmosphere.

For the barrels the lead should be from ⅜ in.

to ½ in. thick. The lesser thickness being for those made of drawn lead pipe or sheet lead turned up and having ladle-burnt seams and the heavier substance when the barrels are cast.

When suction pipes are laid in ground which has lime or old mortar in it they will become corroded and have holes eaten through them. Even when the upper courses of the brick steining of a well have been embedded in mortar and the suction pipe has been passed through, or built in, it has been injured by the above action. Hence the advisability of preventing contact by surrounding with clay, dry bricks or other suitable material.

With regard to the strength of the handle, which is usually made of iron, the greatest strain is near the plank pin, or fulcrum, and this part requires to be stronger than those near to which the power is applied or the weight suspended.

The rule for finding the strength is the same as that for a beam fixed at one end and loaded at the other, and is :—

Multiply the transverse strength of iron in lbs. by the breadth and by the depth squared in inches and divide by the length also in inches.

From the Ordnance experiments* the mean transverse breaking weight necessary to break a bar 1 in. square, projecting horizontally 1 in. beyond the support, the weight being at the free end, is 7,102 lbs. If we divide this by 4 we have 1,775 lbs. as being a load it would carry in safety.

If we assume that a pump handle is 42 in. long from the centre of the plank pin to the part gripped by the hands, and is 1 in. square in section at its strongest point, we then have

$$\frac{1775 \times 1 \times 1^2}{42} = 42{\cdot}26 \text{ lbs. as the weight}$$

it would safely support at the end of the handle if it were horizontal and the short arm rigidly fixed.

As the man pulls down with a power of only

* Molesworth.

about 20 lbs. the handle appears to be twice as strong as is necessary and could be reduced to one-half its sectional area. But it must be remembered that the 20 lbs. was assumed as an average for continuous work. At the commencement of the stroke the power is above this, although it lasts only for a fraction of a second. And, again, if a reduction is made it should be in the width and not in the depth. If this were done we should then have the handle at its strongest part ½ in. wide by 1 in. deep. The width would be so small that any side motion of the handle would probably bend it, and for this reason the width of 1 in. should be retained for stiffening purposes. Another reason why the width should not be reduced is because so small a surface of the handle hole would rest on the plank pin that they would mutually wear each other away very quickly. For large pumps which require two men to work them, or for lift pumps for raising water to great heights, or to tanks at the tops of high houses, the strength of the handles should be increased beyond the example dealt with. Such increase should be in the depth of the section in preference to the width.

The remainder of the handle can be gradually reduced in thickness, lesser strength being required as the power, or man's hands, is approached. But this reduction must not be made to the extent of the actual strength required, or the lower extremity of the handle would be so thin as to be uncomfortable for gripping. In practice a bulb is generally made at the end, not only for this reason, but, as before explained, to aid the worker by its weight when pulling down.

We may now deal with the thickness of the bucket rod. The average breaking weight per circular inch of wrought iron is 15·7 tons, and for circular ⅜ in. 550 lbs.† As these are the breaking weights we should make an allowance for safe working, which is usually considered as one-fourth, so that we must divide 550 by 4,

† Clarke's Tables.

which gives 137·2 lbs. as being the weight safely carried by an iron rod $\frac{1}{8}$ in. in diameter. Where the water has a corrosive action on lead and dissolves some of that metal, iron immersed in such water rusts with very great violence, and the substance of the bucket rod is reduced considerably and much weakened. If for this we divide by 8 instead of 4 we have 68·75 lbs. as being the weight which can be safely lifted by a rod $\frac{1}{8}$ in. thick after it has been reduced by corrosion to the assumed extent.

We have before worked out the weights lifted when pumping, but may take another example to save reference.

Say a 4 in. pump and 25 ft. from top of bucket to water in well.

Then $4^2 \times \cdot 34 \times 25 = 136$ lbs. to be lifted. To this should be added the extra friction of the water at the commencement of the stroke, and also that of the bucket in the barrel. After doing so, we find that a bucket rod $\frac{1}{8}$ in. thick is only half the strength required for the work to be done. Although theoretically correct, a rod twice as strong, or ·178 in. thick, would not do at all in practice. The motion is a pull and thrust one, and the worker would sometimes be "jerky" in his movements. And with a jack pump the movement of the rod is not always in a vertical line, but in a slanting direction, as the top end rocks to and fro in the front and back sides. To have the necessary strength and stiffness bucket rods should be not less than $\frac{3}{8}$ in. to $\frac{5}{8}$ in. in diameter, according to the size of the pump.

Hitherto we have dealt with ordinary lead jack pumps fixed above the level of the ground, but there are many cases where the well water has been so low down that pumps so fixed were useless. In many country places the water, although low, is within a reasonable distance, and a jack pump is made for the purpose, thus avoiding the cost of a "lift pump" and its fittings

Assuming the water to be 35 ft. below the surface, and the pump is required to raise water to fill a cart, the top of which is 7 ft. above

ground level, the men standing on a raised platform to work the handle.

In such a case the bucket must work within the limits that have been already laid down.

Then $35+7=42$ ft. the water has to be lifted. If we take the limited distance between the well water and bucket at 25 ft. we have $42-25=17$,

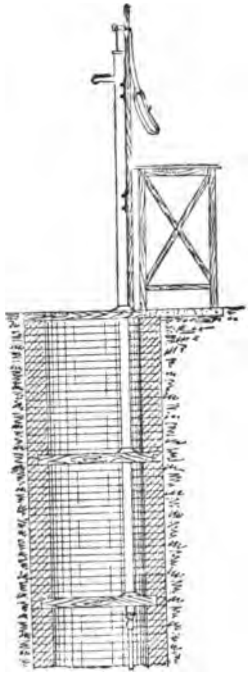

FIG. 16.

and the pump sucker must be that distance from the top of the barrel. A pump for this purpose should have a very long barrel, the total length of which should be $17 +$ extra length at top to form a head, or say 18 ft. in all. Such a pump is shown fixed in a well by Fig. 16. The barrel fixings must be very strong, and are best made

with wiped flange joints supported on oak stages with the ends built into the steining.

As it would be very difficult to fix the sucker or take it out for repairs if as shown by Figs. 1 and 5, a different kind is necessary. Spherical, or ball, valves, as shown by Fig. 17, can be used. The ball and seating are made of

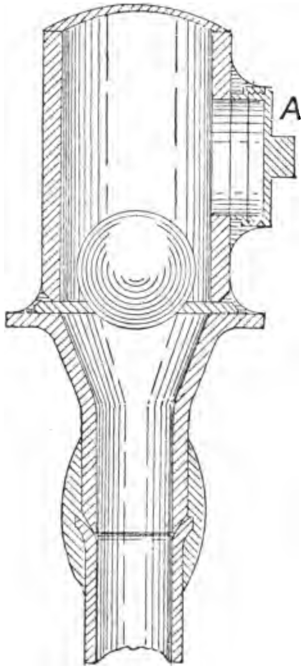

FIG. 17.

gun metal and soldered between the barrel and tail piece, as shown by the fragmentary section. This valve, to be taken out for any purpose, requires a "door" in the side of the barrel, as shown at A, and which consists of a good size, very strong brass or gun metal cap and screw wiped in. The disadvantages are, grit prevents

the valve "seating" properly; the ball can be changed, but not the seating, without unsoldering the joint to the tail piece ; and, if the pump is being worked very quickly, and the ball rises too high, a considerable quantity of water "slips" before the valve reseats itself.

Another kind is shown in section by Fig. 18. This is a "ground-in" valve with a "feather" guide on the under side and a "bow" top for lifting out with a hook on a rod through the top end of pump.

A valve, either "ground-in" or with a leather washer, and with a very long spindle, as shown by Fig. 19, is sometimes used. This valve has a guide for the spindle to work in, and can be lifted similar to the last one. A disadvantage of this valve is that, in fixing it, two joints are necessary. The body has first to be soldered to the top end of the suction pipe, and a second joint made between the latter pipe

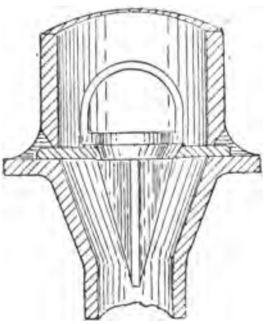

FIG. 18.

and the barrel. Unless great care is taken the first joint is liable to be melted when making the last one.

There are many other methods adopted, but the simplest is shown by Fig. 20. With this valve the seating is raised so that grit or very small pebbles fall on one side and do not make the valve leak. The latter can be lifted out

from the top of the barrel to have the leather B renewed. The brass seating should have a flat top, instead of an edge which would cut into the leather. The spindle is very long to prevent the valve jumping out of its position. The end of the spindle is pointed, and the hole through the guide bar "mouthed" for the more readily dropping the valve into its position. The water-way is as large as possible so that the valve does not rise too high, when pumping,

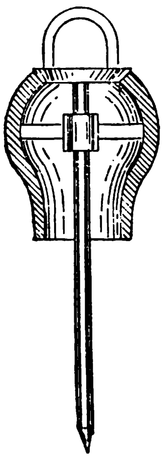

FIG 19.

with consequent less "slip" in recovering its seating.

Pumps with very long barrels do not have such long strokes as those with short barrels, as the rocking motion of the top end of the rod, as before referred to, knocks against the front and back sides of the top to a greater extent. To prevent this knocking the arc described by the end of the short arm of the handle has to be reduced, and by so doing the length of stroke is shortened and less water delivered.

Another kind of jack pump is when two nozzles are necessary ; the lower one for filling

pails, &c., and the higher one for carts, or, as experienced by the writer, filling the copper at a small country brewery. Such a pump is shown by Fig. 21. The lower nozzle has a cap screwed on the end when the upper one is being used. The figure also shows a compound pump handle, which can be used when the man

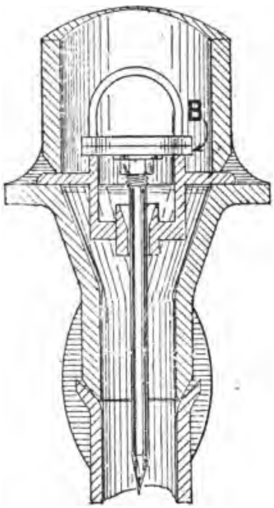

FIG. 20.

is standing on the ground instead of on a raised platform. By this arrangement there is only a slight, if any, gain of power. As an example, assume that the short and long arms of the top lever are 6in. and 9in. respectively, that the pump has a 4 in. barrel and has to raise water 25 ft. above the well water measured to the under side of nozzle, which gives 136 lbs. net weight to be lifted.

Then $\frac{6\text{ in.} \times 136\text{ lbs.}}{9\text{ in.}} = 91$ lbs. of power to be applied to the long arm of the upper lever. If

the short arm of lower lever is 9 in., and the long arm 36 in. we then have

$$\frac{91 \text{ lbs.} \times 9 \text{ in.}}{36 \text{ in.}} = 23 \text{lbs. nearly}$$

as the power to be applied to the end of the lower lever, which is the same as if it had been

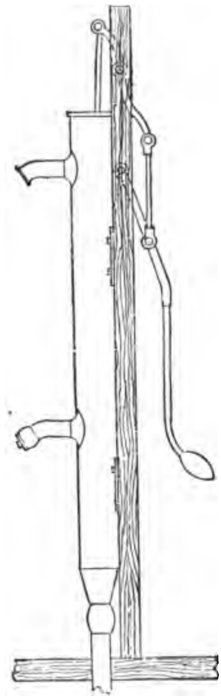

FIG. 21.

connected directly onto the pump bucket. If to this is added the preponderance of weight of lever over bucket, and an allowance for friction of the latter, we find that an ordinary man could work the pump. If the bolt connecting the rod of the upper lever to the lower one was moved

one or more inches nearer to the plank pin of the latter more power would be exerted, but the length of bucket stroke would be reduced, resulting in less water being delivered at each completed stroke.

Where two men are necessary for working a pump it is an advantage to make the handle double, that is, have a large bow, as shown by Fig. 16, so that each man can grip independently of the other, and individual energy be exercised to the utmost extent. When 6 in. or larger size pumps are used they can be fitted with two handles mounted on the same axle, from which projects an arm for attaching to the bucket rod. Pumps with two handles and two

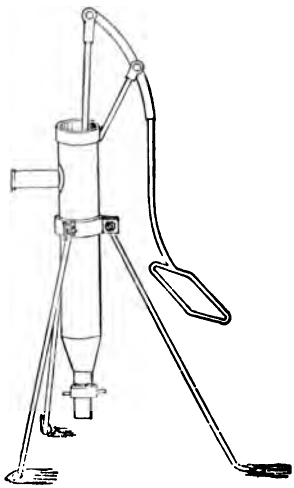

FIG. 22.

nozzles are sometimes fixed in cottages in the country.

In addition to lead, jack pumps are made of other materials, such as cast iron, brass, gun metal, and galvanised sheet iron. The latter kind is generally mounted on an iron tripod, as shown by Fig. 22, and is known as a contractor's

pump. Instead of an iron tube suction, a flexible hose is sometimes connected by means of a brass union, a rose being attached to the lower end of suction where necessary for preventing anything passing up with the water to clog the sucker and bucket valves. A great many are used in country places with flexible suctions for emptying cesspools or filling carts with water from streams, ponds, and ditches, &c., for farm and other purposes. The water carts sometimes have pumps fixed to them.

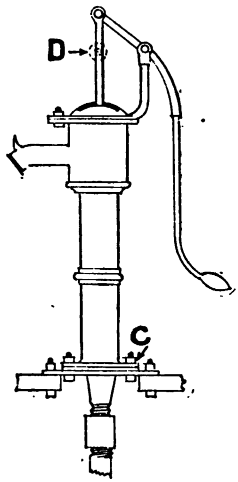

FIG. 23.

Ordinary contractor's pumps have galvanised sheet iron suctions, which are made in lengths and have what may be termed coned joints. The upper end of each pipe has a trumpet mouth, into which the length above is tightly socketted and the joint made with clay.

Cast iron pumps are now much used. Some kinds can be bolted to a base and do not require any planks or other supports. Such pumps have a flange connection between barrel and tail piece, as shown at C, Fig. 23. The bottom valve or

"sucker" consists of a piece of leather cut as shown by Fig. 24, and is bolted between the bottom flanges. With some pumps the clack, shown in the centre of the last figure, has a

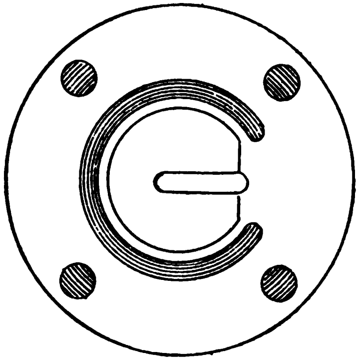

FIG. 24.

stud on the top of the side next the hinge which stands up as shown by the sectional Fig. 25. This prevents the clack opening too wide and

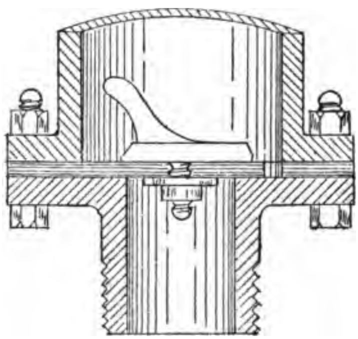

FIG. 25.

is useful for emptying the barrel in frosty weather. On raising the handle to the utmost extent the bucket rests on the stud, opens the valve and allows the water to run away down

the suction pipe. Some of these pumps have brass union connections to the tail piece instead of being screwed for iron, as shown in the figure, and instead of the flange for fixing to a stone or oak base have lugs cast on the barrel for fixing to a plank or a wall. Others again have cast iron brackets for bolting to walls as fixings. Nearly all iron jack pumps have iron caps or covers on the top of the barrel similar to that shown in the last figure. The hole for the bucket rod to work in is slotted to allow for the rocking motion that has been before men-

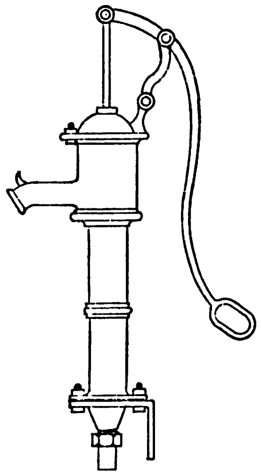

FIG. 26.

tioned. These pumps have many other forms, besides the one shown, and amongst these may be mentioned those having the handles mounted in slotted projections on the sides of the head. With these the bucket rods work beneath instead of through the cappings or covers.

With those pumps having the rod working through the top, and to avoid the latter being slotted the handles are mounted on "swivels" or "vibrating links," as Fig. 26, which also shows a base bracket for bolting to a wall.

This bracket to be at the side and not under the handle as drawn. The vibrating link is for the purpose of allowing the bucket rod to work vertically through the cover, the rod being stiffer than for ordinary pumps to resist being

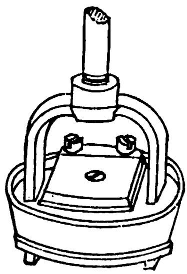

FIG. 27.

bent against the sides of the hole which acts as a guide.

Another maker of these pumps has the vibrating link attached to the short arm of the handle, with a kind of rule joint to the bucket rod, as shown by dotted lines at D, Fig. 23. In this case the handle is mounted on a standard, attached to the pump, higher than that shown in the figure to allow the handle to

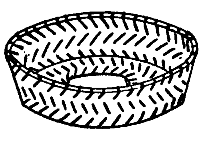

FIG. 28.

be worked without the joint knocking against the cover.

With the cheaper kinds of iron pumps wooden "buckets," similar to that shown by Fig. 2, are used, but these are not nearly so good as those made of brass or gun metal, as shown by Fig. 27.

Pumps of all kinds used for hot liquors should

have "quilted" cups and flanges instead of those made of leather, the latter material being injured by the action of hot water. The cups and flanges are made of

FIG. 29.

specially prepared canvas, which is cut to shape, and then three or four thicknesses sewn together by "overcasting" all the edges to prevent them fraying out. The centre parts are quilted by sewing through, the stitching being evenly done and a short distance apart, to what may be termed a "herring bone" pattern. These can be made by plumbers, but are much better when bought of dealers of plumbers' materials who have them made in a proper manner. Fig. 28 is a sketch of a quilted cup showing the stitching. Buckets with quilted cups for hot liquor generally have ground-in brass valves. Fig. 29 is a quilted bottom or sucker flange.

A great deal more could be written on the various kinds of jack pumps, but as most of the principal points have now been alluded to, and others will be under the next heading, we can now pass on to another description, usually known as "lift" pumps, and deal with them in the same manner as we did with the others, commencing with their various parts and construction.

Lift Pumps.

As a preliminary it may be stated that a lift

pump is used for raising water to a position much higher than itself.

If we were to take a lead jack pump, make the top of the barrel water-tight, and also the hole through which the bucket rod works, turn the nozzle upwards and solder to it a pipe for conveying the water to any desired position, it would then be what is commonly called a "lift pump." Jack pumps are frequently called lift pumps, and the latter "lift and force pumps." In these lectures it is proposed to speak of each kind separately, so as to avoid confusion, and allude to "force pumps" as those having solid plungers or pistons.

A simple, or what may be called home-made, example of a lift pump, as sometimes found in country places, is shown by Fig. 30.

The barrel is lead, and the same as for a jack pump, excepting that instead of an open head a brass stuffing box and flange is soldered on at E. The delivery pipe F is soldered to the side of the barrel, as close to the top as possible. The bucket is made of elm, as for an ordinary jack pump, and the barrel has to be a little longer than usual to allow for the length of the bucket. Brass buckets, as Fig. 702, are also used, and for these the barrel need not be quite so long. The sucker is made of elm, but brass sucker boxes can be bought for cementing into the tail of the pump.

Fig. 31 is an enlarged section of the flange and stuffing box. G is the bucket rod made of copper, H the screw for compressing the stuffing or packing I as close to the rod as possible for preventing the water escaping. J J are the pump screws (the best are made of copper), K is a leather washer, and L a brass flange soldered to the lead barrel. The latter is fixed to a plank M, Fig. 30, by means of strong lead face soldered tacks N, and square headed, or coach, screws with flanged heads, as at O. The pump handle P is mounted on an oscillating link Q and axis R, which is screwed to the plank.

On referring to the illustration it will be noticed that no valve is shown on the delivery

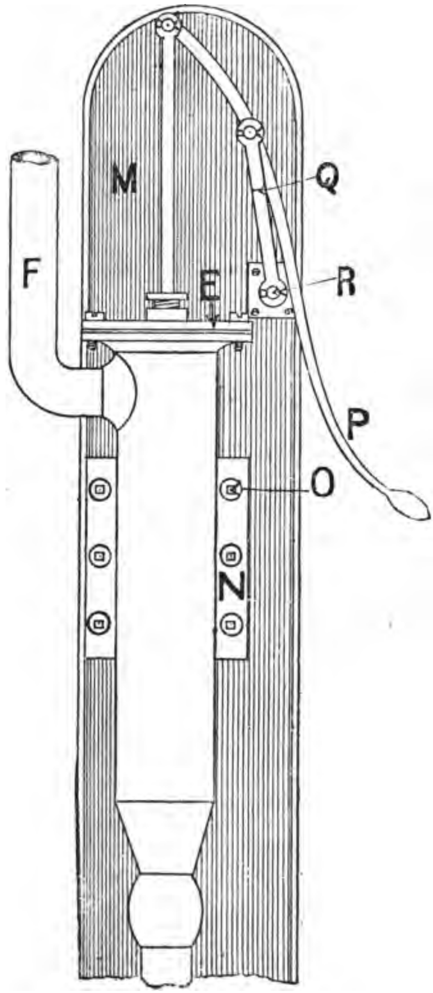

FIG. 30.

pipe. Neither is one necessary, excepting in cases where the lift is very high. With low lifts, say 10 ft. or 20 ft., it may be considered an advantage not to have this valve, as should it be required to recharge the barrel with water, prior to working it, this can be done by pouring down the delivery pipe. With a valve fixed, and it was sound, the water could not run into the barrel.

Lift and force pumps have the length of their suction pipes limited to the same extent as jack pumps, and should never be fixed more than 25 ft. above the well water. And it necessarily follows that in a deep well the pump has to be fixed inside and below the ground surface. In such a case it would be supported on a plank,

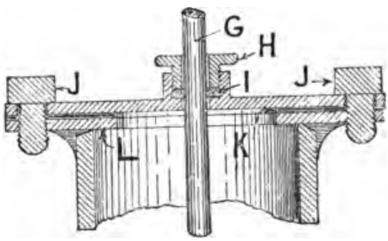

FIG. 31.

fixed either to the steining or a platform, and worked by a handle or a winch above the surface of the ground, but immediately over the well, and a long bucket rod to the pump.

Under these conditions a valve and air vessel should be fixed on the delivery pipe, as close to the pump as possible.

Hand-made leaden lift pumps are not now so much used as those made of brass or gun metal. An illustration of the latter is shown by Fig. 32. The barrel S is brass or gun metal, as are also the tail piece T and stuffing box U. The rod V is copper and continued through the iron guide W, which has a brass bush for the rod to work through. The sling X is made of wrought iron and connected to the handle Y and the bucket rod V by the bolts A. The use of the

sling and guide is to keep the rod straight and prevent it vibrating. But for these the rod would be either bent or worn away by friction against the stuffing box. To prevent bending and to avoid the use of the guide and sling the handle could be mounted on a vibrating standard, as shown by Fig. 30 at Q, but this is not nearly so good. With the pump, illustrated by Fig. 32, the axis, or bolt, is in one piece with the handle and works in the carriage B which has brass bushed holes for the axis to work in. When water has to be lifted to a great height a valve is fixed at C and an air vessel (usually made of copper) at D. For a very deep well the pump would have a base flange, and be fixed on a bearer nearer the water. The air vessel being attached to the pump delivery arm and the working handle and plank, fixed at or above ground level, as before stated.

Before describing other lift pumps and their working parts, it may here be considered convenient to explain the use of the air vessel. An enlarged section of this was shown by Fig. 14 to illustrate its use in a suction pipe. Under those conditions the air is rarefied or expanded, but when fixed in the delivery pipe it is compressed or made to occupy a lesser space. A further sketch is here shown, Fig. 33, to aid the description. D is a section of the vessel in which the delivery pipe E is continued through the top and nearly to the bottom. When the pump is first started the vessel is filled with air, but after pumping for some time the water rises and pushes the air into the upper portion where it cannot escape. Assuming that the pump has been worked long enough to fill the delivery pipe, and the water stands in the vessel to the height shown in the figure when the pump and the water are at rest, the next time the handle is pulled down more water is forced in and the air further compressed, say to the dotted line, F. The labour of compressing the air is not nearly so much as would be required to suddenly overcome the inertia of the water in the delivery and put it in motion. But as the air is compressed

to a greater degree than is exercised by the

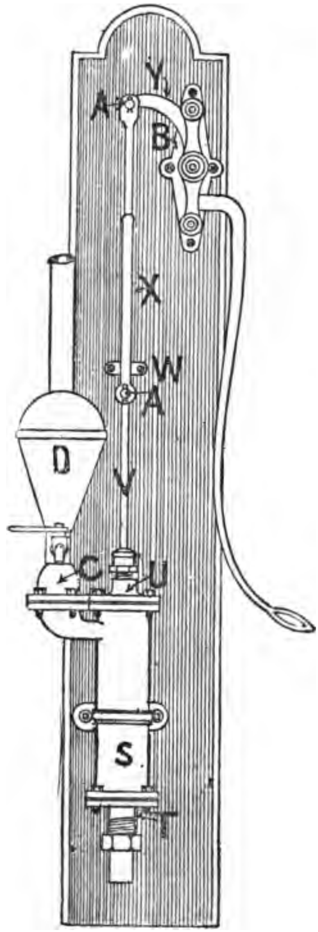

FIG. 32.

dead weight of the water in the pipe above,

it naturally begins to return to its first condition of density at the end of the stroke, and in doing this pushes some of the water out of the vessel and up the delivery pipe. During the time this is occurring the handle is being raised for the next stroke. On pulling it down, the water being already in motion, so much resistance is

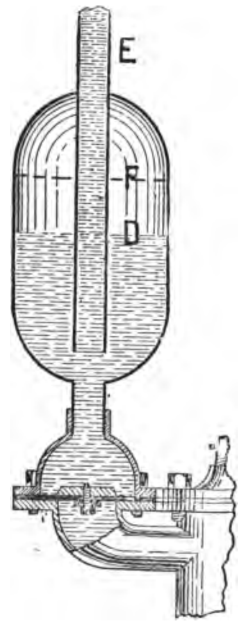

FIG. 33.

not offered and consequently the pump is worked easier.

A few calculations may aid to make clear the economy in labour by using an air vessel. Assuming that the delivery pipe is 100 ft. long, 50 ft. being vertical and 50 ft. horizontal. The horizontal portion has no effect on the pressure but has a considerable influence on the working, on account of the friction of the water when in

motion, and also when starting the pump. The 50 ft. of vertical column of water exerts a pressure of 21·67 lbs. on each square inch inside the vessel. This is found by a previous rule and 50 ft. × ·4334 = 21·67 lbs. We also found that the pressure exerted by the atmosphere at sea level was 14·7 lbs. per square inch, and we may say that the water in this case exerts a pressure of nearly one-and-a-half atmospheres. A volume of air confined in any vessel simply fills it under ordinary conditions, but it will hold twice the quantity when the bulk is reduced by an additional pressure of one atmosphere, or the original quantity would only half fill the vessel under the same additional influence.

To more fully explain this we may refer to what is known as "Boyle's Law," which is as follows :—*The temperature remaining the same, a volume of a given quantity of gas is inversely as the pressure which it bears.*

For demonstrating this principle a glass tube on a stand, as shown by Fig. 34, and known as a Boyle's tube, is requisite.* The end, G, is sealed or made perfectly air-tight. A little mercury is poured in the open end, H, until the tube is filled to O, or zero, on the two scales, which are in this case divided into inches, on each side of the bend. Some little trouble is required to do this owing to the air being slightly compressed in the short leg, but by tipping the tube two or three times success can be attained. In this condition the air pressure on the mercury is the same in both tubes.

We have before demonstrated that the ordinary atmospheric pressure is equal to a column of mercury 30 inches high. If the long leg of the tube is now filled with mercury to a height of 30 inches, measured from the surfaces of the two columns, as shown in the figure, the air in the short leg will be found to occupy half the space it did at first, thus showing that with double the pressure the air is reduced to a space equal to half its original bulk. If we were to

* On the Continent this is known as Marriotte's tube.

add mercury in the long tube to a further height of 30 inches, as dotted line at I in the figure, this would be equal to another atmosphere of pressure, and the pent-up air in the short leg would be further reduced to one-third its

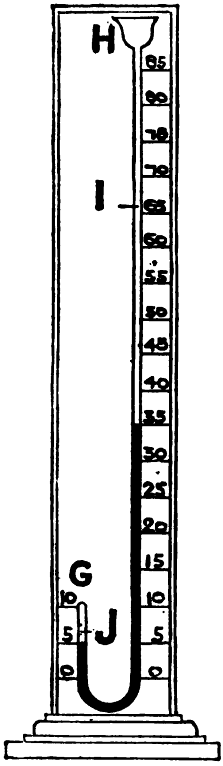

FIG. 34.

original bulk, the mercury rising to J. Another 30 inches of mercury would again reduce the confined air when it would be contained in one-fourth the space it did when starting the experiments.

The following table is calculated on this basis and the assumption that the ordinary pressure of the atmosphere is zero.

No. of Atmospheres.	Air compressed in volume in air vessel.	Space occupied by water in air vessel.	Height of column of water in delivery pipe.	
			ft.	in.
1	0	0	0	0
2	½	½	33	10½
3	⅓	⅔	67	9
4	¼	¾	101	7½
5	1-5th	4-5ths	135	6
6	⅙	5 6ths	169	4½

In our pump problem, with 50 ft. head of water in the delivery pipe, we have, as before stated, about 1½ atmospheres compressing the air in the vessel, and which would reduce it to about 5-12ths of its original bulk. The approximate working of this we get from the second column of the table where the pressure of one additional atmosphere reduces the air to one half, and two atmospheres to one third. Then $\frac{1}{2}+\frac{1}{3}\div 2=\frac{2\cdot 5}{6}$ and this reduced to a simple fraction = 5-12ths for 1½ atmospheres.

Fig. 35 is a diagram showing more correctly the amount of compression that takes place from unity to ten atmospheres. To avoid having too many lines to interfere with the clearness of the drawing, the bottom side is divided into atmospheres and sub-divided into spaces, each representing 5 in. of mercury. The side of the figure is divided to represent the amount of air compression which takes place from two to ten atmospheres, and the curved line the height of the surface of the water under the various pressures. By this illustration intermediate readings can be taken. As an example, assuming

the air vessel to have parallel sides and flat ends, and that the top and bottom lines in the figure represent the ends. At what height would the water stand under a pressure of 15 in. of mercury or half an atmosphere above zero? On looking up the third line from 1, it is found to cut the curve at K. Or where would the surface of the water be under 70 in. of mercury? This is equal to two atmospheres + two of the division lines, and it is found to be at L.

At the commencement of the stroke sufficient effort has to be exerted to raise the weight of the 50 ft. column of water above the pump + an allowance for friction in the total length of 100 ft. of delivery pipe. For the pressure on the pump bucket due to head we have (assuming a 4 in. pump) $4^2 \times \cdot 34 \times 50 = 272$ lbs. In the absence of exact data to work from we will

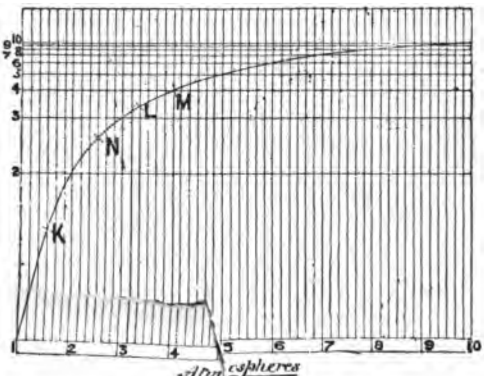

FIG. 35.

assume that the friction in starting movement in the water is equal to 30 per cent. of the load being lifted. And 272 + 30 per cent. = 353·6 lbs. dead weight at the commencement of the stroke when no air vessel is used.

With an air vessel the load is considerably less when starting to pump, as the water is forced into a chamber against the resistance of the contained air which, although compressed,

is so elastic that it can be made to occupy lesser space. The compressed air offers a resistance equal to the weight of the column of water or 272lbs. only. If, at the commencement, the handle was pulled down very quickly, so that the contents of the pump barrel were forced into the air vessel before the water in the delivery pipe had time to be put in motion, the pressure would be sufficient to reduce the air space to the same extent as about an additional 1½ atmospheres. In such a case the water line would be at M, Fig. 35, N being the height before starting. From this we conclude that the friction in the delivery pipe is reduced to almost nothing at starting, and less labour has to be exerted under the given conditions.

And then again, assuming that a pump is being worked at the rate of 30 strokes per minute, one second being occupied in the up- and one second in the down-stroke. The barrel is emptied in every alternate second and, without an air vessel, the motion of the water is arrested and restarted during the same times. But with an air vessel the motion is continuous during both up and down strokes, and, speaking approximately, the friction of the moving water is reduced by about three quarters. This is based on the rule that friction increases as the square of the velocity.

An air vessel has another advantage in that a pump so fitted will last considerably longer, and the bucket will not work loose or break away from the rod so frequently as without.

The noise made by the rush of water through the pipes, and also the thud at each stroke are both minimised by the use of a confined body of air which acts as a cushion or spring.

The above reasoning applies to air vessels in suction as well as in delivery pipes.

There is an impression in some parts of the country that a hopper head and nozzle fixed on the upper end of a pump delivery pipe, as shown at V, Fig. 36, has the same effect as an air vessel fixed to the pump. When the latter is being worked the water is forced at each stroke into the head faster than the nozzle will take it

away, and continues to flow during the reverse action of the pump, thus giving the impression that the water is in motion in the delivery. This is not so, as the water in the rising pipe alternately stops and starts in unison with the action of the pump. The only advantage of the head is the reduction of the plunging noise made by the water falling into that in the cistern. A common complaint in country mansions, where cisterns are fixed in roofs over bedrooms, is the thud made by the water as it is forced into the cisterns. By fixing a head and continuing the nozzle to nearly the bottom of the cistern, as shown by dotted lines, the splashing noise is not heard. The head should be partially covered but have an air opening, otherwise, with a defective pump, the contents of the

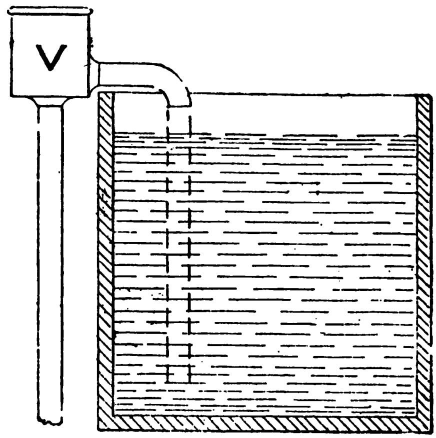

FIG. 36.

cistern would be syphoned back into the well. For reasons that have been fully dealt with an air vessel should always be fixed to the pump by which water is raised to any considerable height.

We may now deal with the size of the handle

and power necessary to work a pump under the conditions mentioned on page 51. Assuming it is fixed 20 ft. above the surface of the well water.

Then 20 ft. + 50 ft. = 70 ft. total height the water has to be raised. And $70 \times 4^2 \times {}^{\cdot}34 =$ 380·8 lbs. to be raised by the bucket. If the short arm of the handle is 6 in. long and the man can pull down with his hands with a power of 20 lbs. we have $\frac{380{\cdot}8 \text{ lbs.} \times 6 \text{ in.}}{20} = 114{\cdot}24$ in., or a little over $9\frac{1}{2}$ ft., the length necessary for the handle. Such a length could not be worked, and if the handle was double, but half the length, so that two men could use it, it would then be over $4\frac{1}{2}$ ft. long. This goes to prove that under these conditions a 4 in. pump could not be used, and a smaller size should be fixed. We could work out experimentally what smaller size pump would do, but the readiest way will be to apply another rule and find the smallest actual size at once. Expressed as a formula it would be :—

$$D = \sqrt{\left(\frac{L \times P}{W \times S}\right)}$$

Where D = the diameter of the pump in inches.

L = length of long arm of handle in inches.

S = length of short arm of handle in inches.

P = power of man in lbs.

W = weight on each circular inch on the bucket in lbs.

In our problem we will assume that

L = 36 in.
S = 6 in.
P = 20 lbs.
W = $70 \times {}^{\cdot}34 = 23{\cdot}8$ lbs.

Then

$$D = \sqrt{\left(\frac{36 \times 20}{23{\cdot}8 \times 6}\right)} = 2{\cdot}24 \text{ in. nearly}$$

as the largest diameter of the pump that could be used under the given conditions.

Here another detail has to be taken into consideration. If a given quantity of water has to be raised the smaller size pump has either to be

worked more quickly or for a longer period of time. The speed should not be increased at the risk of breaking some part of the fittings, so the time must be extended.

To work out an example. If a given quantity of water is raised in one hour by means of the 4 in. pump, how long would it take the $2\frac{1}{4}$ in. pump to raise the same quantity, all other conditions being equal? The simplest solution is to compare the sizes of the barrel. As stated in an earlier lecture, *circles are to each other as the squares of their diameters.* Then $4^2 \div 2{\cdot}25^2 = 3{\cdot}16$ and $3{\cdot}16 = 3$ hours $9{\cdot}6$ minutes to raise the same quantity of water as the 4 in. did in one hour.

Practically there is no great difference in the amount of work that can be got out of a lift pump, whether it is fixed above or below ground level, provided the well is not an extraordinary depth, and it is the same with the barrel fixed in a well to raise water to the ground level or fixed above ground to fill a tank placed at the same height above as the pump was below. In other words, if the suction and delivery pipes are respectively of the same vertical length. In the former case the weight of the long bucket rod would, or should, be compensated by loading the end of the pump handle.

Lift pumps on planks are sometimes worked by means of winch handles, as shown by Fig. 37, or the winch and plank are fixed above ground, as Fig. 39, and the barrel in the well. Even when not actually necessary the barrel, when in cold or exposed positions, is sometimes best below ground and beyond the reach of frost, a cock being fixed near the pump for emptying the delivery or rising pipe.

The power of a winch is calculated by rules almost similar to those of a lever. Let Fig. 38 represent a flywheel, winch and crank. The distance from the handle O to the centre of the crank shaft P being 20 in., and the length of the crank 5 in., measured from its centre to that of the shaft. The 20 in. will be the length of the long arm of a lever, and the 5 in. that of the short arm. Then 20 in. $\div$ 5 in. $= 4$ as represent-

ing the number of times the power of the long arm is over the resistance of the short one. A man working at a winch can exert with his hands an average pressure of about 30 lbs. for

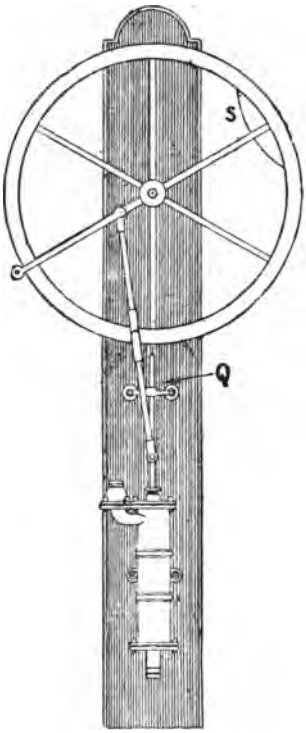

FIG. 37.

continuous work, but for a short time this could be exceeded.

From this we can deduce a formula for finding what size barrel and to what height the water can be raised by a man working the pump shown by Fig. 37.

For finding the actual weight that can be lifted the rule is

$$W = \frac{P \times L}{S}$$

Where P = the man's power.

L = the distance between the handle and centre of crank shaft.

S = the distance between centres of crank and shaft.

W = the weight that can be raised.

And P = 30 lbs.

L = 20 in.

S = 5 in.

$$\text{Then } W = \frac{30 \times 20}{5} = 120 \text{ lbs.}$$

To apply this rule: To what height could a

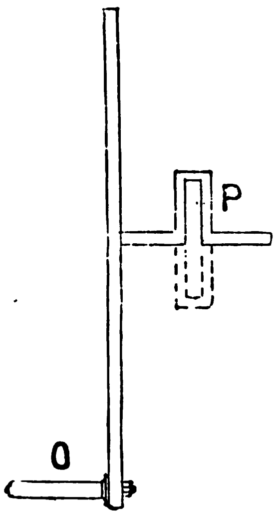

FIG. 38.

man raise water with a 3 in. pump under the foregoing conditions?

Then $3^2 \times \cdot 34 = 3 \cdot 06$ lbs. weight for each foot in height the water is to be raised.

And $120 \div 3{\cdot}06 = 39{\cdot}2$ ft. total height measured from surface of water in the well to the top end of the delivery pipe. So that the work done and power exerted shall not be equal to each other, as worked out in the problem, the height to which the water is raised should be less than that given.

As another example: What is the largest size pump, fitted as Fig. 37, that could be used for raising water to a height of 60 ft. above that in the well?

The formula then becomes

$$D = \sqrt{\frac{P \times L}{S \times H \times W}}$$

Where P = man's power in lbs.

L = distance of handle from centre of crank shaft in inches.

S = distance of crank between centres in inches.

H = height to be lifted in feet.

W = weight of water on a circular inch in the barrel for each foot of head = ·34 lbs.

D = diameter of pump in inches.

Then

$$D = \sqrt{\left(\frac{30 \times 20}{6 \times 60 \times {\cdot}34}\right)} = \frac{20}{4{\cdot}08} = 4{\cdot}9$$

and $\sqrt{4{\cdot}9} = 2{\cdot}213$ in. as the diameter sought. Here again an equilibrium is established, and the pump should be a little less, so that power may exceed load.

From this working out we are led to the conclusions that the pump mounted as shown by Fig. 37 is only satisfactory when of a small size, or used for raising water to a moderate height.

The flywheel has an advantage in that, when fairly heavy, it steadies the action of the pump. By its momentum it carries the motion of the pump beyond those parts where the man can exercise the least power, such as when the handle is horizontal with the axis.

When the pump is fixed in the well, and the plank and winch above ground, the guide Q should be attached to the plank, so that the

motion of the bucket rod is always vertical If the sling and guide were attached to the pump the rod would rattle very much, and in its oscillating movements would be liable to bending between the guide and winch.

Another wheel action is shown by Fig. 39. When the pump is fixed below ground the wheel is mounted on a plank, and instead of a

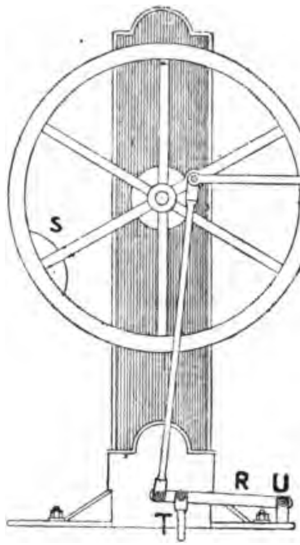

FIG. 39.

guide and sling to the pump rod, a rocking bar, R, is fixed.

S S, Figs. 37 and 39 are counterpoises for balancing the weight of the rods and handles which are on the opposite sides of the axles of the fly wheels.

Not only is the rocking bar R, Fig. 39, useful for steadying the pump rod, but by its use there is a gain of power. To explain this, assume that the combined weights of the rod T, and the bucket and water in the barrel are 360 lbs. If

the bar is 18 in. long, the centre, or the rod bolt 3 in. from the short and 15 in. from the long end, the long arm of the lever is five times the length of the short one and supports 1-6th of the load. The other 5-6th hangs on to the winch crank. Then 1-6th of 360=60 and 5-6th of 360=300 lbs. From this we find that

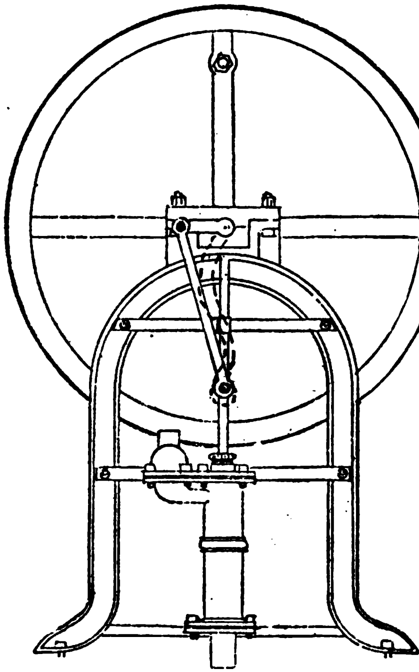

FIG. 40.

when working a pump under such conditions the load on the crank is lightened by 60 lbs.

A case came under the writer's notice a few years ago where the plumber, with a view to lengthening the stroke of the pump so as to throw more water, altered the connections to the rocking bar and attached the pump rod

near the short end. The pump then worked so hard that one man could use it for only a short time. A calculation will show why this was so. Assuming that the weight to be lifted and other conditions were the same as in the last problem but the couplings where changed, we should have 360 lbs. hanging on the end above T, Fig. 39. By adopting our lever formula as described in an earlier lecture we get

$$\frac{360 \text{ lbs.} \times 3 \text{ in.}}{15 \text{ in.}} = 72 \text{ lbs.}$$

as the weight that would be hung on the end of the bar, represented by the resistance of the bolt U, to balance the weight hanging on the other end, as 72 lbs. × 15 in. are equal to 360 lbs. × 3 in. The net weight being 360 lbs. and the counter balance equal to it the actual weight to be lifted by the man when pumping is twice that or 720 lbs. By this will be seen the great increase of labour entailed by the alterations that were made by the plumber.

A winch pump and frame with the front half of frame removed, is shown by Fig. 40. With this appliance, two men on opposite sides of the frame can work, and by doubling the manual power, water can be and is raised to a much greater height than by a pump with a single handle at which one man only can exercise useful effort.

When the water exceeds 25 ft. below the ground level the winch should be on the surface and the pump in the well.

On referring to the figure it will be noticed that the handles (one being shown by dotted lines) and crank are at right angles to each other, and these are the best relative positions. The greatest effort is required when the crank is horizontal, as the greatest weight is then being raised, and the bucket is travelling at the highest speed. With the handle either up or down, when the crank is in the above position, the worker either pulls or pushes, and his power may then be taken at a pressure or force of about 40 lbs. When the handle is horizontal it is equal to only about 20 lbs., and if the crank was parallel with the handle he would not be

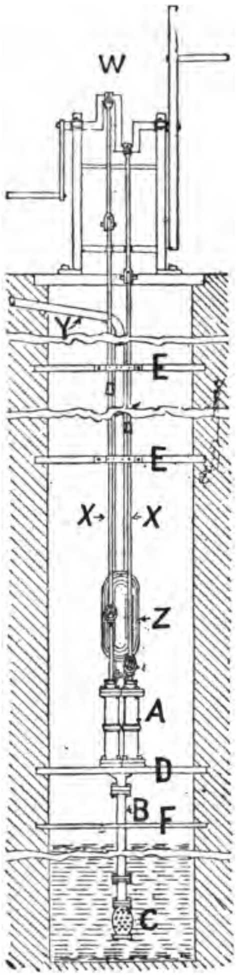

FIG. 41.

F

exercising his greatest power at the time the heaviest load was hanging on the crank. It was on this basis that the 30 lbs. average pressure by a man's hands was computed. The momentum of the fly wheel helps to make his efforts more continuous and regular.

Fig. 41 shows a double barrel pump fixed in a well, W being the winch and frame, X the pump rods, Y the rising main, and Z the air vessel. The pumps are shown at A, the suction at B, and the strainer at C; D, the pump carriage or platform, and E the rod guides and stages. In many cases the pumps have flange bases, which are screwed onto oak stages, the ends of the latter being built into the steining or well walls. To prevent tools, &c., falling into the water when doing anything to the pumps, joists should be fixed and a floor laid two or three feet below, as shown at F. Most of our leading pump makers supply cast iron pump stages and shoes; one of these is illustrated by Fig. 42. The shoes or end pieces G G, are built into the steining, and the stage H, is bolted to them.

Fig. 43 is a view of a cast iron roller guide for the rods and support for the rising pipe. If the rods did not have some form of guide to steady them they would rattle very much, and any vibrating movement would tend to bend or break them, and also injure the copper bucket rod or its connections to the iron. The rollers are made of brass or gun metal. When made of iron they rust and do not revolve properly. When dirt or grit falls into the well, or any small pieces of earth or rock fall off the well sides, or scales of rust peel off the iron rods, the rollers sometimes get jambed, hence the necessity of fixing sheet metal capping pieces or other provisions for throwing off the pieces of grit, stone, &c. Some old well hands prefer oak stages and cleats, but they are not so good as the roller guides, as in wet wells they become soddened and wear away to such an extent that the pump rods do not work true.

The clip I, Fig. 43, is for supporting the delivery pipe, and is fixed by means of screws

which should be made of copper. When the pipe is made of lead small flanges should be soldered on to rest on the clips and thus avoid bruising the pipe by screwing the clips tight enough to grip it. The strainer at C, Fig. 41, is for preventing anything being carried up with the

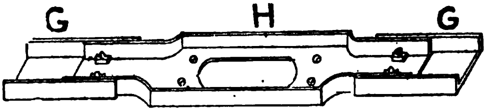

FIG. 42.

water to injure or choke the bucket and sucker valves. Although sometimes made of iron, copper is preferable, as the sizes of the holes, or perforations, do not become changed by the corrosion of that metal in the same way as with iron. A "foot valve" is sometimes fixed near the strainer. One is shown in partial section by Fig. 44. A clack valve similar to that shown by Fig. 25, but without the spur, or as at the bottom of the air vessel, Fig. 33, is bolted between the two flanges. By some plumbers this valve is looked upon as essential to the working of a pump, but is not so. If muddy water is being raised the suction valve does not always close properly, and with the additional valve at the foot there is the prob-

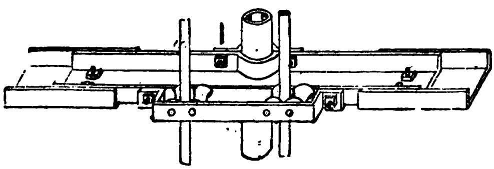

FIG. 43.

ability that the two would not be affected at the same time. In such cases the valve may be considered of advantage. And so, too, when

the suction is horizontal and of considerable length. With the foot valve the pipe can be filled with water and so expedite getting useful effect out of the pump. The position of the valve renders it difficult to execute repairs. For this reason many that are fixed are never repaired and, although out of order, the pumps still answer satisfactorily. Another disadvantage of the valve is, when in order, the pipe cannot be emptied, when it is necessary to do so, without considerable trouble.

With long lengths of pump rod it is necessary to couple them in a simple, easy, way so that there is very little trouble in making the connections in the well or disconnecting them when necessary. Fig. 45, J shows an elevation of the joint when coupled, and K with the brass socket slipped up to expose the method of dovetailing the ends of the iron rods, which are made square in section. This method is very strong and, when properly fitted, cannot get out of order.

The joint of the iron to the copper rod is shown by L, Fig. 45. The loop is welded on to the iron, and the copper rod has a long screwed thread with two nuts for connecting to the loop. By this arrangement the exact length of the combined rods can be carefully adjusted.

Iron well rods are made in 12 ft. lengths, and from $\frac{5}{8}$ in. to $1\frac{3}{8}$ in. in thickness, according to the size of the pumps. These vary from 2 in. to 8 in. in diameter. The copper rods are always supplied with the pumps, and their thickness is about the same as the iron ones. The sizes of rising and suction pipes for double barrelled are the same as for single pumps. As only one pump at a time is raising water there is no necessity for increasing the sizes, excepting for very high deliveries, or when the pumps are worked at a high speed, when friction of the water passing through should be allowed for and larger sizes fixed. When ordinary cast iron is used the friction is greater than with lead pipes, and in this case, too, the sizes should be increased. The following table of sizes may be found useful for double-barrelled pumps :—

Diameter of pump barrel.	Diameter of cast iron suction and rising main.	Diameter of lead suction and rising main.
2½ in.	1½ in.	1¼ in.
3 ,,	2 ,,	1½ ,,
3½ ,,	2¼ ,,	1¾ ,,
4 ,,	2½ ,,	2 ,,

With two barrels the labour of working is slightly increased over that of a single one. To explain this we may take it that the rods balance each other, and the man has to exercise his greatest effort when the crank that is lifting is in the middle of its stroke, that is, when it is horizontal. The other crank is also horizontal, but is travelling downwards. When rising, the man has to again use extra effort, and this occurs twice during one revolution of the cranks. With a single pump this happens only once.

As there are limits to a man's strength it becomes necessary at times to add to it by mechanical appliances. Hitherto we have been dealing with such appliances, but have not exhausted them in our pump problems. Whenever we vary speed, power, or work done, it is always at a gain or sacrifice of something else.

When making calculations as to the amount of work done, fixed data must be used, and these data must be based on an average of experiments. Dealing with a man's power of carrying loads, a man can bear about 300 lbs. weight for a short time when standing still, but he could not carry it any distance. If it was reduced to 200 lbs. he could carry it a short distance on the level, and if it was further reduced to 100 lbs. he could carry it double the distance. Time, too, has to be taken into consideration. A given amount of work can be done in a given

time, but double the time is necessary to do twice the amount of work.

The standard of power for moving machinery is based on the average strength and endurance of a horse. What is known as a horse-power is equal to a weight of 33,000 lbs. lifted one foot high in one minute. But if 3,300 lbs. were lifted ten feet high in one minute, or the same weight raised one foot in one-tenth of a minute, the result would be considered equal to one

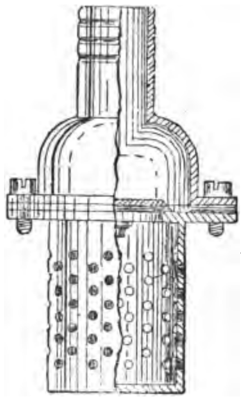

FIG. 44.

horse-power. And the strength of a man working at a winch is calculated on similar lines. With an ordinary winch pump of a given size he can raise a certain quantity of water to a certain height in a certain time, but if he has to raise a larger quantity, the time must be increased or the height reduced, as his strength is a constant that cannot be varied excepting by mechanical appliances.

If water has to be pumped to a height which requires strength beyond that of an average man when working at a winch, what is known as a "wheel and pinion" motion can be attached. This increases the applied power, but lowers the speed of the pumps. The man exercises his

average strength and turns the wheel the same number of revolutions in the same time, but the crank which actuates the pump rod turns only

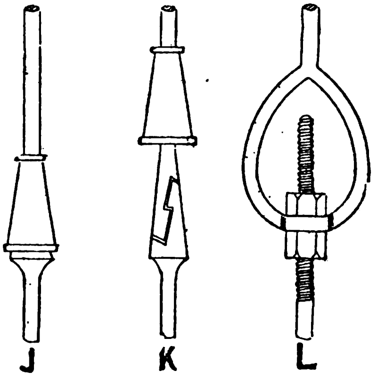

FIG. 45.

half or one-third the times of the wheel, as the gearing is in the proportion of two to one or three to one.

Fig. 46 represents a plan of a pump-frame

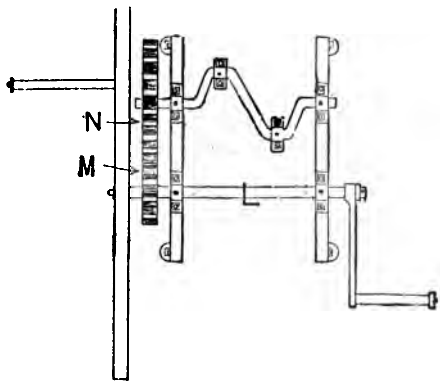

FIG. 46.

with wheel and pinion motion. The fly-wheel

and handles are mounted on the shaft L and at M is a small cog-wheel, which turns the larger one N. If the number of cogs in the small wheel is 10 and the larger one 20 the power is doubled, but the speed at which the crank shaft revolves is only half that of the fly-wheel. If the large wheel had three times the number of cogs of the small one, the power would be increased three times, but only one-third the quantity of water would be raised in the time an ordinary direct-acting pump would do the work. And so on for other rates of gearing.

We will work out an example of such a pump. Assume a pair of 3 in. pumps with gearing 20 to 10 (or 2 to 1) to raise water to a height of 200 ft. The distances of crank and handle from centre of shaft being 5 in. and 18 in. respectively.

Then $3^2 \times \cdot 34 \times 200 = 612$ lbs. net weight of water to be lifted, to which should be added an allowance for friction of the moving parts of the pump.

To find the power to be applied to the winch the rule is :—

$$P = \frac{C \times W}{L}$$

When P = The Man's power.
C = Length of Crank.
L = Distance of handle from centre of shaft × rate of gearing.
W = Weight or load to be lifted.

$$\text{Then} \quad P = \frac{5 \text{ in.} \times 612 \text{ lbs.}}{18 \times 2} = 85 \text{ lbs.}$$

Or if the gearing is three to one

$$P = \frac{5 \text{ in.} \times 612}{18 \times 3} = 57 \text{ lbs. nearly}$$

These are far above an ordinary man's capabilities for continuous work, and if we divide the results by 30 lbs., which we have before assumed as a fair value, we get 3 and 2 approximately as being the number of men required to work the pump under each of the given conditions. And to these we may add in each case, one additional man for labour absorbed by friction and excess of power over load.

By another rule we can find the size of the pump that one man could work under the given head of 200 ft. and 2 to 1 gearing, the crank and handle being 5 in. and 18 in. as before. The rule is :—

$$D = \sqrt{\left(\frac{L \times 2 \times P}{C \times {\cdot}34 \times H}\right)}$$

Where D = diameter of pump barrel in inches.
L = distance of handle from crank shaft.
2 = rate of gearing.
P = man's power = 30 lbs.
C = length of crank in inches.
·34 = weight of water in 1 ft. of 1 in. pipe.
H = height to be lifted in feet.

Then

$$D = \sqrt{\left(\frac{18 \times 2 \times 30}{5 \times {\cdot}34 \times 200}\right)} = 1{\cdot}8 \text{ in. nearly.}$$

With a pump of this diameter the power and load are in equilibrium. To have an advantage of power over load the pump should be smaller than that worked out, especially bearing in mind that no allowance has been made for friction of working parts and of the water in the pipes.

The height of 200 ft. that we have been working on may seem extraordinary, but there are numbers of wells which are that depth, and in some parts of the country even deeper.

In practice it is found at times necessary to have double-handled winches, as shown by Fig. 46, so that three or four men can work at the same time. In such cases it is difficult for each man to exert his power in unison with the others, and the value of 30 lbs per man should be considerably reduced. For large pumps and very deep wells it is necessary to employ horse, steam, or other power, instead of men. This will be referred to at a future time.

We will now work out a few examples of water raised by deep well double barrelled pumps.

How much water is raised in one hour by a

pair of 4 in. winch pumps with 12 in. strokes worked at the rate of 25 per minute?

Then

$$4^2 \times \cdot 034 \times 1 \times 25 \times 60 \times 2 = 1632 \text{ gallons.}$$

How long would it take with the last pump to raise 20,000 gallons?

Then

$$\left(\frac{20{,}000}{\cdot 034 \times 4^2 \times 2 \times 25 \times 60}\right) = 12 \text{ hours } 15 \text{ minutes.}$$

What size pumps would be necessary to raise 930 gallons in one hour, the other details being as in previous questions?

Then $930 \div 2 = 465$ gallons raised by each barrel and

$$D = \sqrt{\left(\frac{465}{\cdot 034 \times 25 \times 60 \times 1}\right)} = 3 \cdot 0 \text{ inches.}$$

With a pair of 4 in. winch pumps geared 2 to 1, how much water would be raised in one hour, 12 in. stroke, the fly-wheel revolving 25 times per minute?

With this gearing the cranks revolve and the pumps work at half the speed of the fly-wheel.

Then

$$\left(\frac{4^2 \times \cdot 034 \times 1 \times 25 \times 60 \times 2}{2}\right) = 816 \text{ gallons.}$$

How long would it take a pair of 4 in. pumps with 10 in. stroke, geared 3 to 1, to raise 1000 gallons, the fly-wheel being turned at the rate of 25 times per minute?

Then

$$\left(\frac{1000 \times 3}{\cdot 034 \times \frac{10}{12} \times 4^2 \times 2 \times 25 \times 60}\right) = 2.206 \text{ hours.}$$

Treble Barrel Pumps.

Pumps with three barrels are chiefly used for raising large quantities of water. The power required for working them is a little more than for double pumps, and has to be applied more evenly. That is, it must be constant, as no matter in what position the handles may be, one of the cranks is always rising and water is being lifted or forced up the delivery pipe. Fig. 47 is a side view of a "three throw" crank with the ends of the pump rods attached. Assuming

that the revolutions are in the direction of the arrow, the crank O is on the point of commencing its upward travel and begins to lift water before P is immediately over the shaft, until which time it is also doing effectual work. Q is travelling downwards, and on arriving at the position O will then commence to do effectual duty. By a careful study of the figure it will be noticed that the worker has to apply his power during the whole of the revolution, and not vary it quite so much as in the case of single and

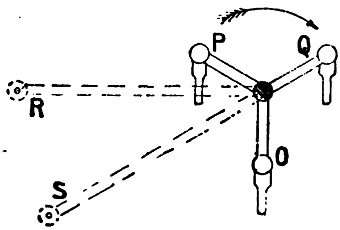

FIG. 47.

double pumps. Neither does it make much difference as to the relative angle formed by the handle with the cranks. When the handle is in the position R the load is a little less than when it was at S. In this latter position the crank P is horizontal and further from the centre of gravity, hence the weight or load is greater at that instant of time than when in any other position. And this occurs three times during one revolution of the crank shaft. With a heavy fly wheel, and worked at a fair speed, the difference in amount of applied power would not be noticed by the worker. But if turned very slowly the man would find that as each rising crank arrived at a horizontal position he would have to exercise a slightly greater effort Not suddenly applied, but gradually increasing as the crank rises to that position, and diminishing as it approaches the centre of gravity, which is immediately over the shaft.

For raising water with a "three-throw" pump to a moderate height, and with small size barrels,

one man can work it. But for deep well work gearing is necessary, as was explained for "double-throw" pumps.

With the pumps we are considering, when being worked, the water is always in motion, both in the suction and delivery pipes. The motion is not quite constant, but varies according to the position of the cranks. That is, the speed of the buckets increases as the cranks approach the horizontal, and diminishes as they pass above it. The speed of the water in the pipes is in proportion to that of the upward travelling bucket. From what has been explained we conclude that air vessels are not so necessary for treble barrel pumps as for those with double and single barrels, unless they are worked at very high speeds. Large numbers of three-throw pumps are fixed without air vessels or chambers. The sizes of the latter for all kinds of pumps are varied according to the height the water has to be raised. For the kind of pumps usually fixed by plumbers they are from about four to ten times the capacity of one barrel.

The positions in which treble pumps are fixed are governed by the same rules as the others that have been described, and it is unnecessary to repeat what has been before stated. As an aid to understanding the duty performed by treble barrel pumps we may work out a few examples, the rules previously given being also applicable in these cases.

How much water can be raised by a 4 in. three-throw pump in one hour with 12 in. stroke, the handle being worked at 20 per minute?

For one barrel we have :—

$4^2 \times \cdot 034 \times 60 \times 20 = 652 \cdot 8$ gals.

And $652 \cdot 8 \times 3 = 1958 \cdot 4$ gals. the answer.

How much water would have been raised if the above pumps had been geared at 2 to 1?

Then $1958 \cdot 4 \div 2 = 979 \cdot 2$ gals.

And if geared 3 to 1?

Then $1958 \cdot 4 \div 3 = 653$ gals. nearly.

What size direct action three-throw pumps with 9 in. strokes, the handle worked at 25 per minute, would raise 1,000 gals. in one hour?

Then $D = \sqrt{\left(\frac{1000}{\cdot034 \times \cdot75 \times 25 \times 60 \times 3}\right)} = 2\cdot95$

or say 3 in. pumps.

In the above working ;—

1,000 = gallons raised.

·034 = gallons in one foot of 1 in. pipe.

·75 = length of stroke in decimal fractions of a foot.

25 = strokes per minute.

60 = minutes in one hour.

3 = number of barrels, and

D = diameters of the pumps in inches.

What should be the sizes of the barrels in last problem if the pump is geared 2 to 1?

As the pumps work at only half the speed they must be double the capacity.

Then $\sqrt{(\text{dia}^2 \times 2)} = D$ or the diameter sought.

Or $\sqrt{(3^2 \times 2)} = 4\cdot24$ in. or $4\frac{1}{4}$ in. nearly.

If the gearing were 3 to 1 the barrels would have to be larger still, and the working would then be :—

$D = \sqrt{(3^2 \times 3)} = 5\cdot19$ in. or 5 1-5th in. nearly.

As a final example :—What size three-throw pumps would be necessary to raise 5,500 gals. per hour, if 12in. strokes and the handle worked at 25 per minute, the rate of gearing being 3 to 1?

In this case we have to consider that if the pumps were not geared they would raise three times the quantity.

Then $D = \sqrt{\left(\frac{5500 \times 3}{\cdot034 \times 1 \times 25 \times 60 \times 3}\right)} = 10\cdot$ in. nearly.

Force pumps will now receive attention.

Force Pumps.

The power that can be exerted by "force pumps" is limited only by the strength of the materials used in their construction. By the aid of suitable appliances a child would have little trouble in lifting, or raising, a load of several tons. It is stated that Archimedes made

the assertion that if he had a place in which to fix a fulcrum, by the aid of a lever he could lift the world. And doubtless a body equal in weight to the world could be lifted by hydraulic machinery if the latter could be made strong enough for the purpose, and a suitable base found for placing it. In an earlier lecture a few examples of the power of hydraulic

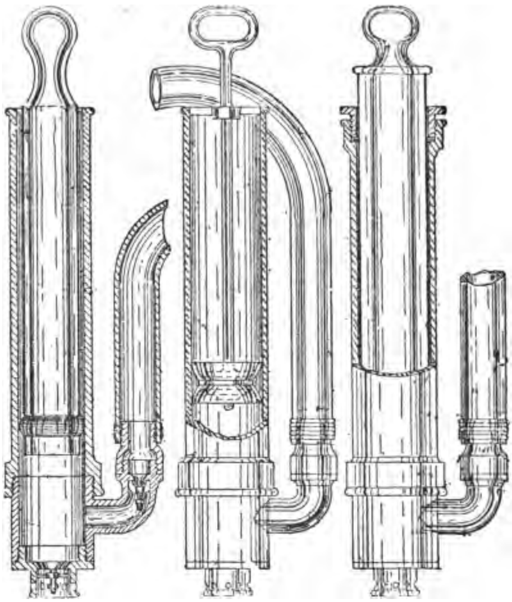

FIG. 48. FIG. 49. FIG. 50.

machinery were explained and worked out, but the methods of generating that power were not dealt with.

It will best answer our purpose to first deal with simple forms of force pumps. Figs. 48 and 49 are sections of those often used by plumbers for removing obstructions in sink and other waste pipes. The only difference between them is, one has a solid plunger or piston with

hemp or similar material bound round near the bottom end, and the other one has two cup leathers mounted on an iron rod. Fig. 50 is another form in which this kind of pump is made. This differs from the others in not having any cup leathers or similar provision, but a stuffing box, or gland, on the top of the barrel to prevent water escaping round the piston. Sometimes the pump shown by Fig. 51 is used. This is the same as Fig. 50, but has a lever handle for working the piston, the short arm of the lever being mounted on a vibrating link fixed near the top of the barrel.

In another form, the pump has a sling and guide instead of a vibrating link.

In each case a "spindle" valve is fixed in the suction end of the pump. Near the bottom of the barrels are branches with valves inside, which open outwards. That is, they allow the water to escape, but not to return. On raising the piston the water is pushed into the barrel by the outside atmospheric pressure, as explained for lift pumps, and on pushing the piston down the water is forced out of the branch. The latter is usually temporarily attached to the end of the pipe which is being unstopped by means of a short piece of very strong canvas or leather hose. The connection is made by inserting the end of the waste pipe into that of the hose and tying loosely with strong cord, which is then tightened by a "twitch" or piece of wood, or a small tool such as a plumber's bolt, which is pushed under the cord, and then twisted round until the joint will resist a good water pressure when exerted inside.

The pressure per square inch exerted by the pumps Figs. 48 to 50 is calculated by the rule :—$P \div A$, in which P equals the man's power of pressing down, and A the area of the end of the piston or plunger. If we assume that an ordinary man can press downwards with one hand with a power of 50 lbs., in addition to an allowance for friction of the piston in the barrel, and that the pistons are 2 in. in diameter in each case, we then have $2^2 \times \cdot7854 = 3\cdot1416$ square inches as the areas of the ends.

Then $50 \div 3{\cdot}1416 = 15{\cdot}9$ lbs. as the pressure exerted per square inch inside the barrel and pipe connections.

To find the power applied for the removal of an obstruction in the waste pipe we first find the area of the surface pressed against and $\times$ by the pressure per square inch exerted by the pump. As an example, if a 2 in. pipe is choked, we then have $2^2 \times {\cdot}7854 \times 15{\cdot}9$ lbs. $=$

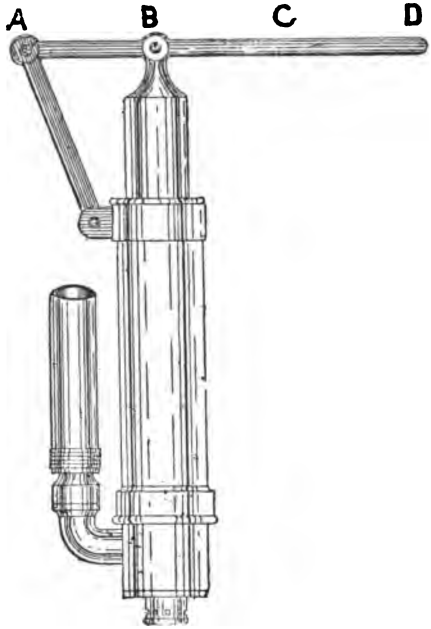

FIG. 51.

49·95, or say 50 lbs., which is the same as was exerted by the man on the piston. If the pipe was 1 in. in diameter we then have $1^2 \times {\cdot}7854 \times 15{\cdot}9 = 12{\cdot}28$ lbs., or only one quarter of the man's efforts usefully exercised.

When the area of the end of the piston and

the diameter of the waste pipe are the same the whole effort of the man is utilised. For instance, if in the latter case, with the 1 in. pipe, the piston had been 1 in. in diameter the whole of the power would have been usefully employed.

By the aid of the pump shown by Fig. 51 the power is considerably increased. To explain this, assume that a man has a yoke on his shoulders and a pail suspended from each end, each, with its contents, weighing 50 lbs. There being two pails of equal weight they balance each other, but the man has to support a load of 100 lbs. And so with the lever handle pump. If the man's power of 50 lbs. is exerted at C, which is the same distance as A from the fulcrum B, the total weight on the latter is 2×50 or 100 lbs., as the resistance at A balances the power at C.

If the lever is extended to D, the length from D to B being twice that from B to A the whole of the power is increased. And 50 lbs. of pressure exerted at D would require 100 lbs. resistance at A to balance it, and $100 + 50 = 150$ lbs. as the weight resting on B. And so on for any other increase in length of the lever.

In a previous problem we found that the pressure exerted in removing an obstruction was in the proportion of the area of the piston end to the diameter of the waste pipe. With the 2 in. piston and 2 in. pipe and the pump shown by Fig. 51, 50 lbs. applied at D would press against the obstruction with a total force of 150 lbs., but with a 1 in. pipe, which is one-fourth the size, the pressure would be only 37·5 lbs. And so on for any other variations.

A great advantage of the force pump for removing an obstruction is, that no matter in what position it may be, even several feet or yards away, or beyond bends which would not allow a cane to pass, the same power is exerted as if it had been near the pump, always provided that the pipe is full of water, and not air. For practical purposes, it is generally assumed that water is not capable of being compressed, or made to occupy a lesser space when under

pressure. That being so, the force exerted by a man with a pump against the object to be removed is in proportion to the same power applied to the end of a solid rod of any hard material, the other end pressing against the obstruction.

The power of a force pump is utilised for testing the strength of pipes, boilers, girders, and many other fittings. Also for generating hydraulic power for moving machinery, working lifts and elevators, and many other purposes.

For testing pipes, boilers, &c., the pump is fixed in a chamber, as shown by Fig. 52. The size of the pump piston is very small, and the chamber holds only a few gallons of water. When a boiler is being tested it is first filled, and then all manholes and connections are made tight. The pipe E is then made good to the boiler and the pump worked. When the boiler is filled, no matter if it holds 10 or 1,000 gallons, it has only to resist the pressure of the contained water, but if only an additional few drops, or a very small quantity more is forced in, the internal pressure is raised to an enormous extent. To explain the increase, we may assume that a cylinder, or cylindrical boiler, 6ft. long by 3ft. diameter, is being tested, and the pump has a 1 in. piston, the lengths of the short and long arms of the lever being 4 in. and 36 in. respectively. The pipe from the pump to the boiler being ½ in. in diameter. Larger sizes are unnecessary, as it is pressure, and not volume, of water that is required.

The area of the piston end being 1^2 in. × ·7854 = ·7854 of an inch. If a 1 lb. weight was hung on the end of the lever at F, the resistance at the other or short end would be found as follows :—

$$R = \frac{L \times W}{S}$$

Where R = the resistance of the link at the end of the short arm.

L = the length of the long arm in inches.

S = the length of the short arm in inches.

W = the weight placed on the end of the long arm.

Then

$$R = \frac{36 \text{ in.} \times 1 \text{ lb.}}{4 \text{ in.}} = 9 \text{ lbs.}$$

This is equal to 10 lbs. resting on the top of the pump piston.

The area of the latter being ·7854 and this $\times 10 = 7·854$ lbs. pressure exerted and this is transmitted to each circular inch inside the boiler. A small deduction should be made for friction of the piston in the barrel, but this is partly overcome by the weight of the long arm of the lever being in excess of that of the short arm.

If a pressure of 50 lbs. was exerted at F, we should then have

$$R = \frac{36 \times 50}{4} = 450 \text{ lbs.}$$

The resistance of 450 lbs. being necessary to balance 50 lbs at the end of the long lever, we have $450 + 50 = 500$ which $\div ·7854 = 636·62$ lbs. pressure per square inch transmitted to the boiler.

To vary the last problem we will assume that the boiler is to work under a pressure of 100 lbs. and that its ultimate breaking strength is 800 lbs. per square inch. What should be the heaviest weight placed on a pump lever at F?

The boiler should be tested, not to destruction, nor to strain and weaken it, but to a point six times above its working pressure, or say 600 lbs.

Then $600 \times ·7854 \times 1^2$ in. $= 471·24$ lbs. to be applied to the top of the piston. The lever is 4 in. + 36 in. = 40 in. long and in the proportion of 1 to 9 and 1-9th of the weight is hanging on the long arm and 8-9ths on the short arm.

Then $$\frac{4 \times 471·24}{36} = 52·36 \text{ lbs.}$$

the heaviest weight that should be applied to the lever at F.

Before going any further with force pump problems we will dwell for a short time on the

strength of the materials necessary for the barrels, &c.

Taking first the pump shown by Fig. 48. We have already found that the pressure inside the barrel is equal to 15·9 lbs. per square inch when the piston is pushed down with a power of 50 lbs. If we assume that for a short time the power could be doubled, the pressure would also be doubled, and for our present purpose we will take it as equal to 32 lbs. per square inch, and the barrel must be strong enough to resist fracture when that force is applied. To allow for contingencies it is usual to take the safe strength of the materials at something below their actual breaking strength. Force pump barrels are usually made of brass, and as that alloy varies very much indeed in its composition a wide margin should be allowed, and 1-6th of its tensile strength taken for safe working. On referring to Molesworth's tables, we find the tensile strength of cast brass is 8 tons per square inch. That is, an average bar of brass, 1 in. square in section, breaks when 8 tons are suspended from it. Then 8 tons $\div$ 6 = 3000 lbs. nearly as safe working strength. If we assume that we are dealing with 1 in. in length of the pump barrel, which is 2 in. in diameter, and that the water inside is divided across the diameter by an imaginary line or space, and that a force in this space is tending to separate the water into two halves, the thrust will act on opposite sides of the barrel and exercise a tearing strain on the material. The diameter of the barrel being 2 in., which $\times$ 1 in., the length we are dealing with, we have 2 square inches. And this $\times$ 32 lbs., the pressure exercised when the pump is worked = 64 lbs. tending to tear the barrel.

Then by rule of three we have

$\therefore$ 3000 lbs. : 1 in. : : 64 lbs. : 0·0213 in.

the thickness of the two sides of the barrel, which $\div 2 = 0·01056$ in., or less than 1-64th of an inch as the thickness of one side to resist being torn by the applied pressure. For practical purposes this thickness would be quite sufficient, but a pump of that substance would be liable to

injury by bruising when being carried about or allowed to lay about the workshop, and should be made stronger, or about 1-16th in. thick.

The strength of the barrel for the pump

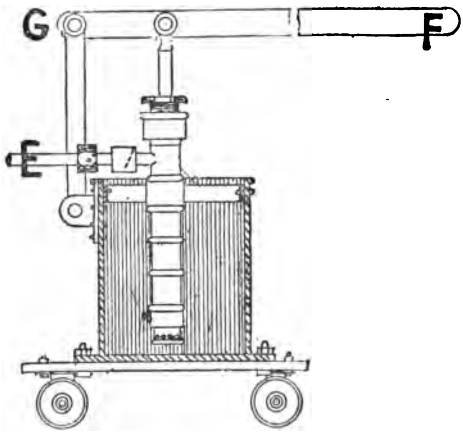

FIG. 52.

shown by Fig. 52, can be found by the same rule. The diameter being 1 in. (more properly speaking it is $1\frac{1}{4}$ in., so that there is no friction of the piston excepting at the stuffing box), and assuming it is constructed to test with a maximum pressure of 2 tons, or 4480 lbs. per square inch. We then have for a brass barrel

$$\therefore \ 3000 \text{ lbs.} : 1 \text{ in.} :: 4480 \text{ lbs.} : 1{\cdot}493 \text{ in.}$$
$$\text{which} \div 2 = {\cdot}746$$

or nearly $\frac{3}{4}$ in. thickness for the sides of the barrel.

And for the boiler, which is made of wrought iron, and has rivetted seams, we have 3 ft. or 36 in. diameter. Molesworth gives an average tensile strength per square inch of wrought iron as 22 tons. If we take the safe strength as 1-6th the breaking strength we have $22 \div 6 = 3\frac{2}{3}$rds tons, or 8213 lbs. If the boiler has to work under a safe pressure of 100 lbs., we have 100×36 in. $= 3600$.

$\therefore$ 8213 : 1 in. :: 3600 : 0·438 which $\div$ 2 = 0·219 in. or a thickness of a little over 1-5th of an inch. As the boiler plates are weakened by the rivet holes a further allowance should be made for this, and double the above thickness used under the given conditions.

The force pumps that we have hitherto dealt with have worked vertically, but it is not

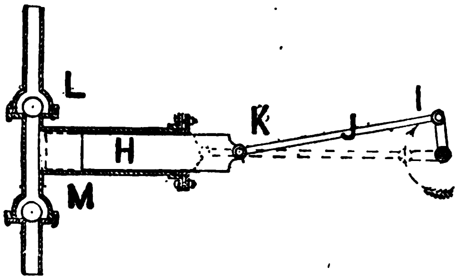

FIG. 53.

essential that they should do so. A great many used for raising water are fixed horizontally.

The section, Fig. 53, is an example in which the piston H is worked directly from the crank shaft I by the connecting rod J, which works

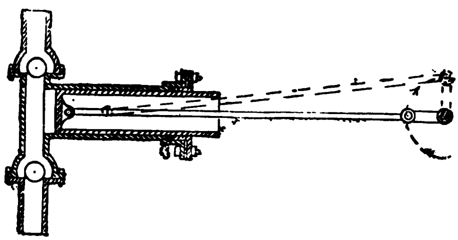

FIG. 54.

on a joint at K. L and M are valves on the delivery and suction pipes. The quantity of water raised at each stroke is equal to the cross section of the piston × the length it is drawn

out of the barrel. Assuming that the piston is 3 in. diameter and travels in the barrel 9 in. The solid contents of the piston being 3^2 in. × ·7854 × 9 in. = 63·6174 cubic inches. And as 1728 cubic inches : 6¼ galls. :: 63·6174 cubic inches : ·23 galls. The barrel may be 4 in., or any other diameter larger than the piston, but the quantity of water raised at each stroke is equal only to the volume of the piston.

To prevent the piston "rocking" in the barrel it is sometimes necessary to have a guide to give it a parallel motion. With the same object in view, force-pumps are made as shown in section by Fig. 54. The piston is hollow and the coupling rod connected to the bottom, or inner end, as shown in the figure. In this case the size of the piston governs the "throw" of the crank. If the latter is too large the coupling rod knocks against the inside of the piston, as shown by the dotted lines, during the revolution of the crank.

Both the foregoing pumps can be fixed in pairs or trebles and worked from the same crank shaft, as was described for ordinary lift-pumps. The manual power to work them is found by previous rules.

A great many force-pumps are worked by direct action of horse or steam, or water-power, but these will be referred to later on.

We will now refer to combined lift and force-pumps. The principles are explained by Fig. 55. In the figure O is the barrel, P the piston with double cup leathers, Q the suction-pipe, R the delivery, SS^1 the suction valves opening inwards, and T T^1 the delivery valves opening outwards. When the piston is rising the valves S^1 and T open and S and T^1 close. When the piston is travelling downwards S and T^1 open and S_1 and T close, the water being pushed up by atmospheric pressure into the barrel or cylinder and lifted out of the upper, and forced out of the lower, portion by the power applied to the pump.

Fig. 56 is a section of one out of a great many that have been patented for use by manual or hand-power. Fig. 57 being a cross

section of the barrel. In pumps of this description it is usual to call the suction and delivery valves "ports." In the drawing the piston is shown working in a barrel, U, and outside the latter is a second one, V, with divisions running the whole length on opposite sides. When the piston is rising water enters the port W, and that above the piston is lifted through X.

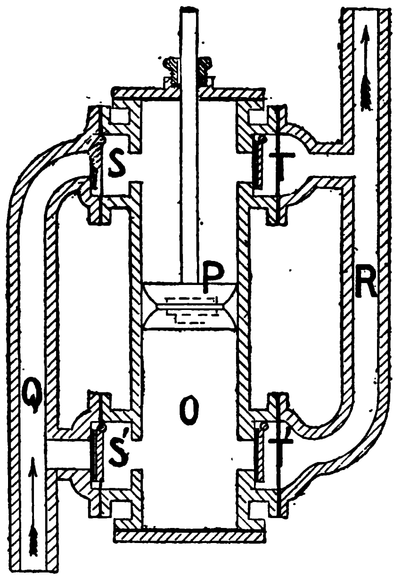

FIG. 55

When the action is reversed water enters at Y, and is forced through Z. A copper air vessel, A, has stuffing boxes at B B, through which the bucket rod C works. The suction D is connected to the well or other water to be raised, and the delivery pipe is connected to the air vessel at E.

This pump is harder to work when a lever handle is used than ordinary lift-pumps, owing

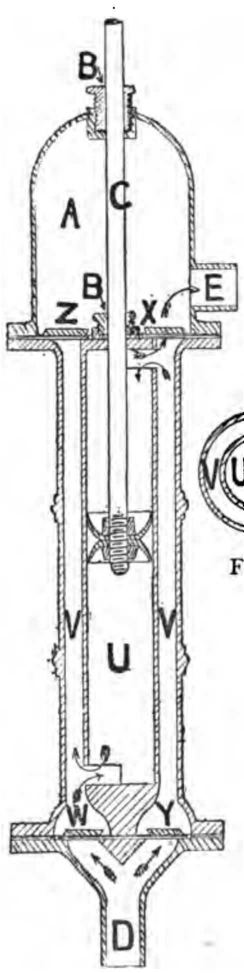

FIG. 56.

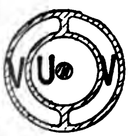

FIG. 57.

to the friction of the bucket rod in the two stuffing boxes, and having to use as much effort when raising the handle as when pulling down. For these reasons it is advantageous to work it with a winch on frame. As much water is raised by it as with a double barrelled pump, the diameters of the working barrels and length of stroke being equal in each case.

Power for Working Pumps.

The powers for working are man, donkey, horse, steam, gas, water and electric. Their relative values are based on the average strength and endurance of a horse. This, for engineering purposes, is assumed to be equal to a load or weight of 33000 lbs. lifted 1 ft. high in one minute. If 33 lbs. were lifted 1000 ft. high in one minute or 330 lbs. were lifted 100 ft. in the same time, it would be considered as 1 h.p. And again, if 3300 lbs. were lifted 1 ft. in 1-10th of a minute, or 330 lbs. were raised 1-10th of a foot in 1-10th of a minute, the work done would still be considered as equal to 1 h.p. Hence the unit of power is called one horse. Multiples and fractions of the same all bear some proportion to the unit above expressed. To compare a man's power to that of a horse, we may take as an example a problem in which a man works at a 4 in. jack-pump with 12 in. stroke at the rate of 30 strokes per minute and raises the water to the height of the nozzle from a depth of 25 ft.

Then 4^2 in. $\times 1 \times \cdot 34 \times 30 \times 25 = 4080$ foot pounds and $4080 \div 33000 = \cdot 1236$. So that the power exerted by the man in this case would be considered as $\frac{1}{8}$th h.p.

Taking another example of a man working a lift pump. Let the pump have 3 in. double barrels with 1 ft. stroke, geared 2 to 1 to raise water 50 ft. high, the revolutions of the fly wheel being 25 per minute. Then

$$\frac{3^2 \times 2 \times \cdot 34 \times 50 \times 25}{2} = 3825$$

And $3825 \div 33{,}000 \doteq \cdot 116$. And this shows the power of the man actually exercised at the winch pump, under the above conditions, to be

a little less than 1-9th horse power. If double the quantity of water was raised to half the height in the same time, or half the quantity was lifted to twice the height in one minute, the proportion of work done would be considered as 1-9th of the unit or standard of work.

In many cases the power of a number of men is utilised for pumping by having a capstan and shafts as shown on plan by Fig. 58, in which E E are the shafts pushed round by the men walking in the track, F F. G G are

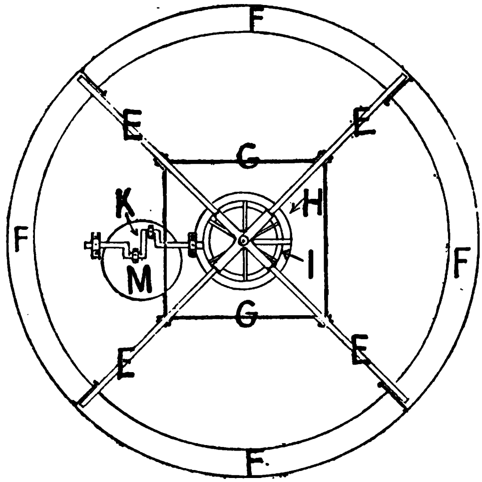

FIG. 58.

the tie rods from shaft to shaft, H is the frame to support the capstan, and the large cog wheel I. The cogs of the latter are on the under side and are toothed into a smaller wheel, J, fixed on the crank shaft, K, from which hangs rods, L, to actuate the pumps fixed in the well M. Fig. 59 is a side view or elevation of the same engine. The reference letters are the same in both illustrations. To find the power or number of men to work the pumps we must have some data to work from.

Assuming the pumps to be 4 in. double barrelled with 9 in. strokes. The centre of the track the man or men walk in 20 ft. in diameter, the applied power being 10 ft. from the centre of the capstan which is turned three times per minute. The large wheel is 3 ft. and the small wheel 6 in. in diameter. The centres of the cranks being $4\frac{1}{2}$ in. from centre of the crank shaft, and the water is to be raised to a height of 100 ft.

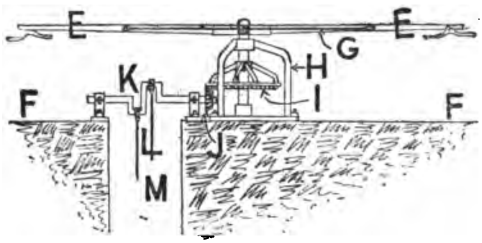

FIG. 59.

To find the work to be done the rule is :—

$$W = H \times d \times {\cdot}34 \times R \times N \times L.$$

Where W = work to be done.
H = height in feet the water is to be raised.
d = diameter of barrel in inches.
·34 = weight of water in 1 ft. of 1 in. pipe.
R = revolutions of crank shaft per minute.
N = number of barrels.
L = length of stroke.
And H = 100 ft.
d = 4 in.

$$R = \frac{36 \times 3}{6} = 18$$

L = 9 in. = ·75 ft.

Then $W = 100 \times 16 \times {\cdot}34 \times 18 \times 2 \times {\cdot}75 = 14688$ foot lbs. per minute.

As pump gearing is generally in a position where moisture or dust and dirt is present, a great deal of the applied power is absorbed by friction caused by rust and grit.

If we assume this to be = to $\frac{1}{3}$rd we then have $14688 + (\frac{1}{3}\text{rd of } 4896) = 19584$ foot pounds.

And $\frac{19584}{33000}$ = 0·59 H.P., or horse power required to do the work.

If we further assume that the gearing shown by Figs. 58 and 59 a man's power is 1-6th that of a horse; then 1-6th = ·166.

And as ·166 : 1 : : 59 : 3·5.

Thus showing that the power of $3\frac{1}{2}$ men is necessary to raise the water under the given conditions.

With regard to the power obtained by the gearing the problem is based on the principles of compound levers.

The crank and small cog wheel have radii of $4\frac{1}{2}$ in. and 3 in. respectively. The heaviest load is when the crank is horizontal, and is found as follows : $4^2 \times {\cdot}34 \times 100 = 544$ lbs.

The length of the lever represented by the length of crank being $4\frac{1}{2}$ in. we have $544 \times 4\frac{1}{2} =$ 2448 in.-lbs. hanging on the crank. To raise this the power to be applied to the small cog wheel is found by dividing the above inch-lbs. by the radius of the latter. And $2448 \div 3 =$ 816 lbs.

This power is derived from the horse or men at the end of the shaft, which is 10 ft., or 120 in., ong, acting on the large cog wheel, whose radius is 18 in.

Then $120 \div 18 = 6{\cdot}66$.

And $816 \div 6{\cdot}66 = 122{\cdot}5$ lbs. to which should be added one-third for friction.

$\therefore$ $122{\cdot}5 + (1\text{-3rd or } 40{\cdot}8) = 163{\cdot}3$ lbs. of pressure to be applied to the end of the driving shaft.

Stated concisely the problem is—

The power to be applied

$$= \frac{4^2 \times {\cdot}34 \times 100 \times 4{\cdot}5 \times 18}{3 \times 120} = 122{\cdot}5 \text{ lbs.}$$

to which add 1-3rd for friction as before = 163·3 lbs.

If this were divided by the number of men we have.

$163{\cdot}3 \div 3{\cdot}5 = 46{\cdot}6$ lbs. of pulling or pushing pressure exerted by each man at the shafts.

For long and continuous work a number of men

would not average the above pressure individually, and in calculations for pumping with a capstan and shafts or levers, a man should not be valued higher than 1-10th of a horse. In our last problem the power required was ·59 of that of a horse, $\cdot 59 \times 10$ would give 5·9, or say six men to do the work. The individual efforts of the men being $= 163 \cdot 3 \div 6 = 27 \cdot 2$ lbs. pressure on the shafts.

With regard to the power of animals, although that of a horse is usually taken as being able to raise 33,000lbs. one foot high in one minute, as before stated, it is only half that, or 16,500 lbs. A pony or donkey is usually assumed to have half the power of a horse, but these animals do not

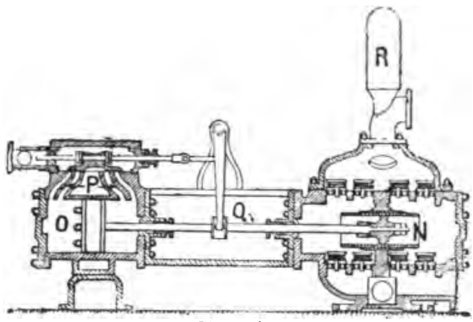

FIG. 60.

weigh nearly or half as much, and they should not be rated at more than ¼ horse power. Bullocks are about as strong as horses but slower in speed.

In addition to steam, gas, water and electricity, hot-air and petroleum engines are also applied to pumping water.

Steam is utilised in several ways. A common one is an ordinary engine with a rigger or pulley wheel fixed on the end of the crank shaft. From this a belt, or driving strap, passes round a similar rigger on the end of the pump crank shaft. This is instead of the winch handle on the left side of Fig. 41. The sizes of the wheels being regulated in proportion to the

speed of the engine and the rate it is desired the pumps are to work.

Another method is to work the pumps by "direct-action" of steam. The principle is explained by Fig. 60, in which N is the pump, O the steam cylinder, and P the steam ports which are opened and closed by the sliding valve. The pumps are usually in pairs and the pistons are connected by rods or shafts, Q. By this arrangement the steam pressure is transmitted directly to the water in the pumps and forces it into the delivery pipe, which has an air vessel, R, for preventing shock in the pipes.

Fig. 61 is a "Beam Engine." The beam, S, rocks on an axis, or trunnions, in the centre, and the motion is caused by the steam in the cylinder, T, the force being transmitted to the pump, U, or to a crank-shaft and fly-wheel for working two or more pumps. The connecting rods to the steam and pump pistons have joints and guides, not shown in the figure, to give them a parallel motion.

Gas engines are worked by exploding small quantities of coal gas and atmospheric air in a cylinder which causes a piston to move and transmit the force of the explosion by means of a pulley on the crank-shaft and a belt to a pulley or rigger on the pump shaft. The shock is steadied, and a continuous motion given by means of a rather heavy fly-wheel, mounted on the same shaft as the driving pulley and piston connection.

"Hot-air" engines are worked by the alternate expansion and contraction, by heating and cooling, of a volume of air in a cylinder heated by coke or other fuel. The pumps are usually worked directly from the engine, but pulleys and belting can be used.

"Petroleum-engines" are worked by exploding the vapour of that oil mixed with air, much in the same way as with gas engines. When these engines are used they should be fixed some distance from the well or reservoir, and care taken that none of the fuel should be spilt or allowed to get into the water.

Gas, hot-air and petroleum engines are all

very useful for small pumping stations, such as are usually found for supplying mansions, farmsteads, and villages, and do not require any extraordinary amount of attention.

"Water power" is much used for pumping both on a large and a small scale and is applied in many ways. There are several kinds of "Hydraulic engines." Figs. 60 and 61, where

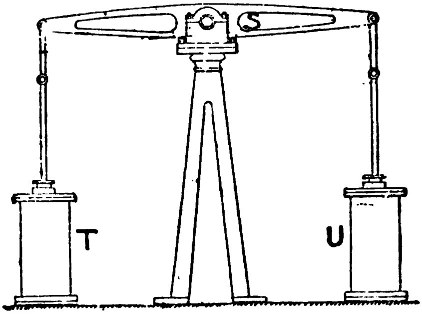

FIG. 61.

made especially for working with water instead of steam, are capable of exerting great power.

Hydraulic rams and double-action, or pumping, rams are doing excellent work in all parts of the country where there are streams or springs of water. Such appliances will be dealt with at a future time.

Water-wheels are another power for raising water. As these machines come under the heading of hydraulics we will here deal with them.

Water Wheels.

Of all the mechanical powers that are utilised for pumping none are of more interest to plumbers than water wheels. Although not made by such workmen they are used in many places, and plumbers frequently have to fix the pumps and pipes in connection with them. In distant country places the wheels are often made by the estate, or village, carpenters or blacksmiths, and it is necessary that the plum-

ber should have some knowledge of their power and working, so as to be able to give advice when called upon to do so, or make repairs when necessary.

Wheels are divided into three classes. Fig. 62 is drawn to enable the student to distinguish them. When the water is discharged onto the top, as at V, it is known as an "Overshot wheel;" when in the centre, as at W, a "Breast wheel;" and when the stream runs beneath, it is known as an "Undershot wheel." The sides of the rims of the wheels are known as "Shrouds."

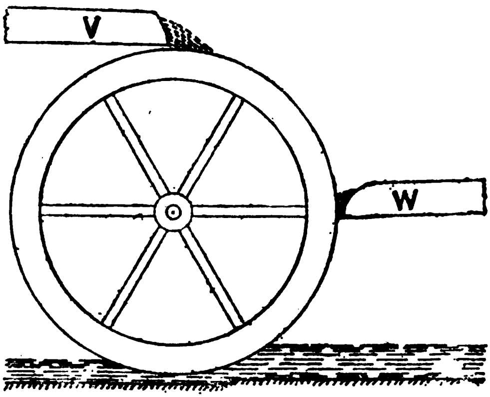

FIG. 62.

The rims of the first two kinds are divided into curved compartments for holding water, and these are called "Buckets." The divisions in Undershot wheels are straight instead of curved, and parallel to the spokes or radii. These divisions are known as "Floats."

Fig. 63, is a diagrammatic side and edge view of an Overshot wheel in which X is a crank attached to the axle. Y the pump, with barrel similar to Fig. 54, but the suction and delivery valves different; and Z, the air vessel and delivery valve. With such wheels the gravity or weight of the water is the motive power, and has the same influence as a weight on the long

arm of a lever. Hence to find the power of such a wheel the quantity or weight of the water retained in the buckets has to be known, and also the length of the series of levers represented by the lengths of the spokes, or to be more exact, the horizontal distance from the centre of the crank shaft to the centres of the buckets. The size of the latter, and the distance between the shrouds should also be known so that their holding capacities may be calculated.

As far as possible the water should be regulated to the size and speed of the wheel. If not so regulated a great deal is wasted by the latter revolving so slowly that the buckets fill to over-

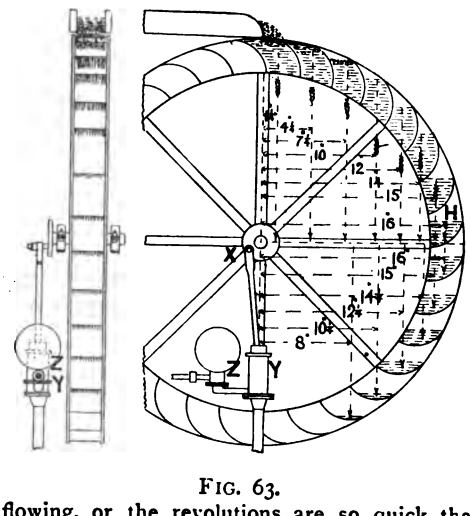

FIG. 63.

flowing, or the revolutions are so quick that they do not fill properly, the water splashing outside. The width of the mouths of the troughs or buckets, or their distance apart, has also to be regulated so that they fill evenly and without shock.

Fig. 63 is a sketch of one of the smallest wheels the writer ever had to do with, and is

drawn from memory. The pump had a $1\frac{1}{2}$ in. barrel, with a 4 in. stroke, the suction and rising main being $\frac{3}{4}$ in. The diameter of the wheel was 36 in., and the length of buckets (or distance between the shrouds) 3 in. The available quantity of water was about 70 gals. per minute, and the height to which pumped about 50 ft. In the figure are broken lines drawn vertically from the loaded buckets to the horizontal spoke, with arrows showing the direction of the pressure caused by gravity. It will be noticed that no two buckets are the same horizontal distance from the axis, and neither do any two hold the same quantity of water. To find the exact power of the wheel would be a tedious task as the contents, or weight, in each bucket would have to be calculated and the distance from the axle measured. But an approximation can be arrived at, and this will answer our purpose. If we take it that the buckets are 3 in. wide, and the depth from the face to the "sole-boards," or bottom nearest the axle, 3 in., the bucket shown at H would very nearly have the capacity of one-fourth of a 6 in. pipe.

Then 6 in. $\times$ 6 in. $\times$ ·34 = 12·24 lbs. of water in one foot of 6 in. pipe.

12·24 $\div$ 4 = 3·06 lbs. in 3 in. of the pipe, and 3·06 $\div$ 4 = 0·76 lbs. weight in the bucket H. If we assume that the weights in those above gradually increase at the rate of ·12 lbs., and those below, that retain water, decrease in the same proportion we have one datum to work from. The others can be measured from a scale drawing, or the distances can be taken as figured on illustration 63.

By a rough calculation we find that the weight of water in the buckets is about 11·48 lbs., which $\times$ the horizontal distance from the centre of the axle the total weight pressing on the horizontal lever, represented by the spoke opposite bucket H, is equal to 110·73 inch-pounds.

Assuming that the size of the pump was unknown, and it was necessary to find what the wheel would work, after allowing one-fourth of

the power as being absorbed by friction, the rule would be:

$$D=\sqrt{\frac{P\times\cdot75}{C\times\cdot34\times h}}$$

In which D = the diameter of the pump.
P = power of wheel.
C = length of pump crank.
$\cdot34$ = weight of water in 1 ft. of 1 in. pipe.
h = height to which water is raised by pump.

$$\text{Then } D=\sqrt{\frac{110\cdot73\times\cdot75}{2\times\cdot34\times50}}=\frac{3\cdot3219}{1\cdot36}=$$

$2\cdot44$ and $\sqrt{2\cdot44}=1\cdot56$ or a little over $1\frac{1}{2}$ in. diameter of pump barrel. The same wheel would work a $1\frac{1}{2}$ in. double-action or double-barrel pump and the motion would be more even. The weight of water in the suction pipe is so small as to have little or no effect on the working.

To find the quantity of water raised by the pump the rule is:

$$g=D^2\times\cdot034\times20\times L.$$

Where g = gallons of water raised per minute.
D = diameter of barrel in inches.
$\cdot034$ = gallons in 1 ft. of 1 in. pipe.
20 = strokes per minute.
L = length of stroke.

Then $g=1\cdot56^2\times\cdot034\times20\times\frac{4}{12}=\cdot5516$ gals. per minute, which $\times60=33$ gals. per hour or 792 per day. If a double-barrel pump was used the latter quantity would be doubled.

When the power of a wheel is calculated to its utmost capacity, it follows that the water supply must be equal to the work to be done. To find the quantity necessary to drive the wheel, we may assume that the periphery is filled 20 times per minute.

To find the contents, we first calculate what the whole wheel would hold and then deduct the centre portion. Then $3^2\times4\cdot9=44\cdot1$ gals. And $2\cdot5^2\times4\cdot9=30\cdot6$ and $44\cdot1-30\cdot6=13\cdot5$, which $\div4=3\cdot37$ gallons the holding capacity if the whole of the buckets were filled to the outer edge of the shrouds. As the wheel revolves 20 times per minute, we have $3\cdot37\times20=67\cdot5$ nearly gals.

required per minute. The water should flow at a little higher speed than the wheel, but the above quantity is sufficient as the speed of the former increases to a slight extent when leaving the trough, as friction then ceases to exercise a retarding influence.

The width of the trough should be less than the wheel, so that the water shall not splash outside the latter. The depth of the water a few inches back from the outlet, assuming the trough to be $2\frac{1}{2}$ in. wide, would be found as follows: Diameter of wheel $\times 3{\cdot}1416 \times 20 =$ $188{\cdot}5$ nearly feet per minute lineal velocity.

Then $67{\cdot}5$ gallons $= 10{\cdot}8$ cubic feet, or $18662{\cdot}4$ cubic inches of water per minute.

$188{\cdot}5$ ft. $= 2262$ lineal inches representing velocity per minute.

And $\frac{18662{\cdot}4}{2262 \times 2{\cdot}5} = 3{\cdot}3$ inches the depth of the water in the trough.

If the water had a fall of a few inches onto the wheel a thinner, or shallower stream would answer the purpose as additional power would be gained from the impulse of the falling water. Too much fall should not be given to cause shock and excessive splashing.

For effective duty done by the pump we may assume that the water falls a distance of half the diameter of the wheel, or say $1{\cdot}5$ ft. The amount used per minute being $67{\cdot}5$ gallons or 675 lbs., we have $675 \times 1{\cdot}5 = 1012{\cdot}5$ foot-pounds from which deduct $\frac{1}{3}$rd. as being absorbed by friction $= 1012{\cdot}5 - 337{\cdot}5 = 675$ foot-pounds effective power per minute.

The quantity raised being $\cdot5516$ gallons or $5{\cdot}516$ lbs., and the height 50 ft., then $5{\cdot}516 \times 50 = 275{\cdot}8$ foot-pounds of work done per minute.

And for the per centage of work done by the wheel :—

As 675 : 100 : : 275·8 : 40·86 nearly.

The speed of 20 revolutions of the wheel or 20 strokes of the pump, should not be exceeded or the latter would soon wear out. If it is necessary for the wheel to run at a higher speed a small pinion could be attached to the axis of the crank X, Fig. 63, and this geared to a larger

cog wheel fixed on the end of a crank shaft to work one, two, or three pumps.

With regard to the power of large size overshot wheels, the principles already laid down apply to them also. In general terms it may be stated that the greater the diameter of the

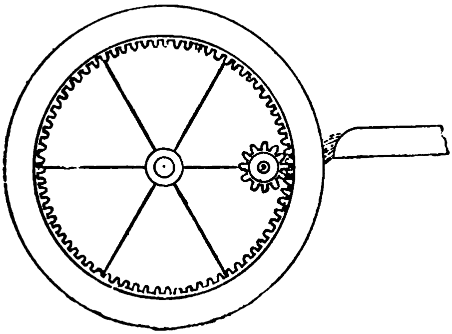

FIG. 64.

wheel the further the weight (water) is removed from the centre of gravity, or distance from the axis measured on a horizontal line, the greater the power. And the longer the distance between the shrouds the greater the holding capacity of the buckets. This again adds to the power in the same way as placing a larger weight on the long arm of a lever would increase the power of that appliance. It is far better to increase the length of the buckets than their depth. With deep buckets the weight of the water is nearer to the centre of gravity, which reduces the power of the wheel, and neither do deep buckets fill to advantage. A thick or deep stream of water on the wheel is not nearly so good as a thin one, and for that reason the small wheel which we took as a text for explaining certain principles should not be accepted as a model. It would have been much better if the buckets had been shallower and two or three times the length, and the power water fed out of a channel or trough about twice or three

times the width. The stream would then have been about one-half or one-third the depth.

With very large wheels the weight on the periphery or rim is very great, and when the pump cranks or other machinery are turned by, or geared to, the axle, the strain on the spokes is a serious matter. To avoid this some wheels have cogs inside the bucket rim, which actuate a small wheel or pinion, as shown by Fig. 64, fixed on the end of the pump crank shaft. The speed of such a wheel should be very slow when used for pumping, otherwise the pumps would soon wear out. If the speed is, say four revolutions per minute, and the diameter of the pinion one-sixth of the wheel, the proportion is one to six, the small one revolving six times to

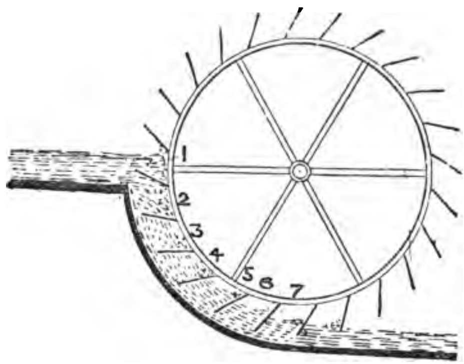

FIG. 65.

the other's once, so that the pumps would make 24 strokes per minute. Should the speed be higher than that given it would be necessary to gear another shaft with cog-wheels of properly proportioned sizes for actuating the pump's crank at the speed best suited to their capacity for working. By additional gearing the friction is increased, and an allowance should be made for this when calculating the power. Fig. 65 is a "Breast" wheel in which the feed water enters the buckets at or near the centre. Some have

shrouds as for overshot wheels, and others work between two walls or similar enclosures, which are so close that very little water can escape past without acting on the wheel. If the buckets are of a good form the water is retained in them until they pass beyond the side walls, whence it flows into the "tailrace" or waste water channel.

For calculating the power of this wheel the *weight* of the water and the *impulse* given by its velocity have to be taken into consideration. If the stream enters the wheel at the level of the bucket No. 1, the *weight* has an effect on all the buckets from 1 to 7. If the water level was lowered to bucket No. 2 the power would be less, as only Nos. 2 to 7 would be influenced.

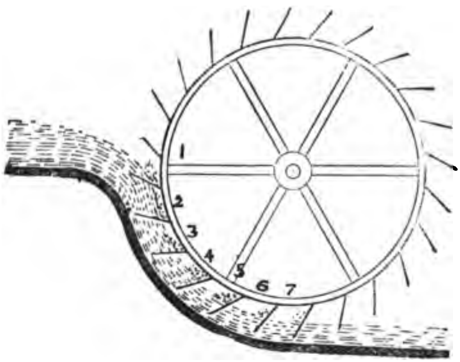

FIG. 66.

And so on until the stream was level with Nos. 6 and 7, when weight would cease to act and impulse only would have any effect.

The velocity of the stream should be such as to give a good impetus to the wheel and exceed the speed of the latter. That is, if the bucket rim travels at the rate of 3 ft. per second the water should flow with a speed of about three times that, or 9 ft. per second. If the wheel and water both travelled at the same speed the

power would be wasted, but when the former travels at a lower speed it offers a resistance to the latter, and it is in pushing that resistance before it that we get what we call "power" out of the water and transfer it to the machinery which is to be put in motion. Although it would be impossible to do so, if the wheel was so fitted that no water could escape past without doing duty, to get the full effect the water, entering at 9 ft. per second, should leave at the velocity of the rim speed of the wheel, or 3 ft. per second, and flow freely away so as not to drown the floats or buckets by backwater.

If the surface level of the water was even with the axle of the wheel, but there was a sloping fall, as shown by Fig. 66, so that the water strikes bucket No. 2, instead of No. 1, as in Fig. 65, the wheel is more powerful, as the impulse is greater owing to the extra velocity attained by the water falling from a greater height. The latter may be only a few inches, but with a large wheel this may represent an increase of one or more h.p. By the same reasoning, if the level of the feed water was raised so that it impinged, or fell on the bucket No. 1, instead of gliding into it, the power would be still more increased.

If the water travels in a straight line level with the centre bucket, as shown by Fig 65, a great deal of the force is expended in knocking against the sole or bottom of the bucket. If the approach is as shown by Fig. 66, the impetus is directed onto the float, or division between the buckets, and the speed of water is increased by the distance fallen. From this we glean that the same quantity of water will, in the latter case, exert a greater power and enter the wheel in a thinner or shallower stream. If the velocity in the feed trough is, say 4½ ft. per second, and at the moment of striking the float double that, or 9 ft., the thickness of the stream would be about one-half at the moment of impact.

To estimate the power of a breast wheel we first find the contents of the buckets, the

quantity of water used and the height from which it falls. Assuming a wheel 6 ft. in diameter, the buckets 1 ft. long and 9 in. deep, the rim velocity to be 3 ft. per second. The mean diameter, measured in the centre of the buckets, would be 5 ft. 3 in., and the circumference at that part 5 ft. 3 in. or 5·25 ft. × 3.1416 = 16·5 ft. The approximate contents if filled would be 16·5 × 1 ft. × ·75 ft. = 12·375 cubic feet, or 773 lbs.

The rim velocity being 3 ft. per second the wheel revolves 6·28 times per minute and 773 × 6·28 = 4854·44, to which add 1-4th as an allowance for waste equals 4854·44 + 1213·61 = 6068 lbs. of water per minute required to work the wheel under the given conditions as to speed.

The total height the water falls may be taken from the surface in the channel, measured a short distance back from the outlet or mouth to the bottom edge of the wheel, or say, 3 ft. The net quantity of water utilised being 4854 lbs., which × 3 = 14562 foot-pounds or $\frac{14562}{33000}$ = ·44 h.p. as the estimated power of the wheel. From this should be deducted an allowance for friction and excess of power over load, which for approximation we may take as 1-3rd. Then 14562 ÷ 3 = 4654 and 14562 — 4654 = 9708 or $\frac{9708}{33000}$ = ·294 net. h.p.

The power transferred to the pump can be found in nearly the same manner as we did for the overshot wheel. The diameter being 6 the radius is 3 ft. The weight of water is about that contained in one quarter of the wheel, as will be seen on reference to Fig. 65. The whole of the buckets, if filled, we have already found to contain 12·375 cubic feet, which ÷ 4 = 3·093, or say 3 cubic feet, or 187·5 lbs. in one quarter of the wheel. For an approximation we may take it that the weight hangs half-way on a horizontal line drawn from the axis to the outer rim or at a distance of 18 in. from the axle.

For finding the diameter of the pump the wheel would work

$$D=\sqrt{\frac{W\times L}{C\times\cdot34\times H}}$$

In which W = weight on wheel in lbs.
L = distance of weight from axis in inches.
C = Length of crank, say, 4 in.
·34 = weight of water in 1 ft. of 1 in. pipe.
H = height the water is to be raised in feet.
D = diameter of barrel in inches.

$$\text{Then } D=\sqrt{\frac{187{\cdot}5\times18}{4\times{\cdot}34\times50}}=\frac{67{\cdot}5}{1{\cdot}36}=49{\cdot}6$$

and $\sqrt{49{\cdot}6}=7{\cdot}04$, or say 7 in. the diameter of the barrel.

The actual working size would be less than this, as such wheels never develop their full working power.

To find the quantity of water that the pump would raise in a given time the rule is :—

$Q=D^2\times S\times{\cdot}034\times N$.

In which D = the diameter of the pump in inches.
S = the length of stroke in feet.
·034 = gallons in 1 ft. of 1 in. pipe.
N = number of strokes per minute.

Then $Q=7^2\times{\cdot}66\times{\cdot}034\times6{\cdot}28=6{\cdot}9$ gals. per minute, or 414 gals. per hour.

For percentage of work done by wheel :

The contents if all the buckets were filled we found to be 12·375 cubic feet, and as they are filled 6·28 times per minute, we have $12{\cdot}375\times6{\cdot}28\times6{\cdot}25\times3=1457{\cdot}15625$ foot-gallons.

And $6{\cdot}9\times50=345$ foot-gallons raised.

∴ 1457·15 : 100 : : 345 : 23·68 nearly.

As the wheel is lifting during only one half of its revolution it follows that half the power is wasted. This could be utilised, and twice the quantity of water raised by using a double barrel, or a double action, pump.

Compared with an overshot a breast wheel is generally assumed to have about 5-6ths the

power, but a great deal depends upon the height to which it is loaded.

Undershot Wheels.

When the water runs beneath the wheel, and acts by impulse only, it is known as an "undershot" and its power is usually considered to be half that of an overshot. These wheels can be fixed in streams and be turned by the current. Where large volumes of water are available, but the streams are shallow, or have very little fall, they are frequently used for pumping water, although they are what may be termed extravagant in the quantity utilised for power.

Where the stream for turning an undershot wheel is wide and shallow, the water should be brought together in what may be called a compact current by means of walls, embankments, or other enclosing boundaries as shown by Fig. 67. Or if the whole of the water is unnecessary for working, the wheel can be fixed in a side stream, as Fig. 68. The latter is the best,

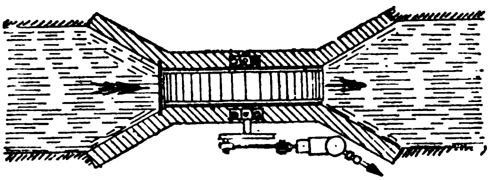

FIG. 67.

as by dropping the sluice at A the wheel B can be thrown out of use when desired. C is a weir for damming back the water for getting a "head." A further advantage of this arrangement is, that where the stream is affected by storms the excess of water can flow over the weir without affecting the wheel. At D is an iron strainer for intercepting floating matters which would clog the wheel.

Many wheels have the "floats" radiating from the periphery, or the flat rim, in the same lines that the spokes radiate from the axis, but it is

doubtful if this is the best method to adopt. When the floats are rising, on the side opposite to the current, they sometimes "pick-up" a portion of the water, and the weight of this detracts from the power of the wheel. When they are of the form shown in the breast wheel, Fig. 65, the water is not carried up to such a great extent.

With what may be called right angle floats the water strikes against them with a shock, rises up a short distance by momentum, and adds slightly to the head. But this extra head is not all gain, as a portion of the power is expended in raising the water to the higher level. This may be only two or three inches, but it is still a slight waste of the power, although to a certain extent compensated by the after downward pressure. With the floats as Figs. 65 and 66 the water glides in and "clings" to the wheel for a longer time, or until the float has risen clear of the tail water, so that more of the force is utilised.

When calculating the power of a current it is necessary to first find the velocity. This is best done by placing a weighted float, so that the bottom as well as the surface, or the mean, velocity can be measured, and noting the time it takes to float a given distance, such as two stakes a measured distance apart driven into the bed of the stream in a line with the current. The quantity can then be calculated from measurements taken of the depth and width, and making an allowance for alteration in depth and speed as it approaches the wheel.

With an undershot wheel the water presses against the floats, and the pressure multiplied by the area of the surface pressed against equals one factor for calculating the power.

The rule for finding the velocity of falling bodies is applicable to this case, and is as follows:—

The square root of the height fallen in feet × 8 = *velocity in feet per second.*

Or, if we know the velocity, to find the height fallen:—*Divide the velocity by* 8 *and square the result*, which gives the answer in feet.

Example: If the water has a velocity of 8 ft. per second, then $8 \div 8 = 1$, and $1^2 = 1$ foot, the head to create the given velocity. Or if the head is 4 ft. then $\sqrt{4} = 2$, and $2 \times 8 = 16$ ft. the theoretical velocity in feet per second.

A cubic foot of water weighs $62\frac{1}{2}$ lbs., and exerts that pressure on each foot of surface exposed to it for every foot of head, and in a stream resists an equal pressure behind it, being itself pushed against.

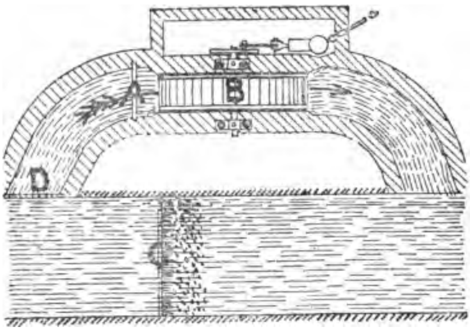

FIG. 68.

In practice the floats should not be totally immersed, or the back-water would react against them and retard their movement. And neither should they be so deep as to dash against the water as they enter the current.

When calculating the power of an undershot wheel the pressure against the first float, which is immersed in the current, only is used. To feed the water to the best advantage a sluice should be fixed for the water to pass beneath and strike the floats when they are approaching the position immediately under the axle. If the sluice is opened so that the water passing beneath is 6 in. deep, and is travelling at the rate of 8 ft. per second, then the head must be 1 ft. to get that speed. The head is measured from the surface of the water on the upper side of

the sluice to the middle of the opening of the latter, so that the actual depth of the higher water is 15 in.

To work out the power of a wheel we may assume a small one 5 ft. in diameter, or 4 ft. 4 in. as a mean when measured between the floats at half their depths, and having shrouds or sides 1 ft. apart. If the velocity of the water is 8 ft. that of the wheel should be about 1-3rd, or say 2·66 ft. per second.

The mean diameter being 4 ft. 4 in. we have 4 ft. 4 in.. or say $4·33 \times 3·1416 = 13·6$ the mean circumference, and $\frac{8 \times 60}{13·6 \times 3} = 11·76$ revolutions per minute. Such a wheel would have about 27 floats and $11·76 \times 27 = 317·5$, or say 317 floats exposed to the action of the water in one minute. Then $60 \div 317 = 0·19$ nearly of a second each float is acted upon.

The stream being 1 ft. wide × 6 in. deep and travelling at the rate of 8 ft. per second = 4 cubic feet which $\times 62\frac{1}{2} = 250$ lbs. of water per second passing under the sluice. Then 19-100th of $250 = 47·5$ lbs. of power exerted on each float as it becomes exposed to the full influence of the water. But the full force is not utilised owing to the wheel being in motion and not at rest. The water travelling at the rate of 8 ft. and the wheel 1-3rd of that, or 2·66 per second, the speed of the former is as 2 is to 1 for the latter. And we may assume that only 2-3rds of the power is utilised. Then 2-3rds of $47·5 = 31·66$ lbs. as the actual water power acting on the wheel in the same manner as one or two men working at a winch.

The mean distance from the axle of the wheel being $30 - 4 = 26$ in. and $31·66 \times 26 = 823·16$ inch-lbs. acting on the axle to turn it round. If we allow 1-3rd of this as being absorbed by friction, and as an allowance for power in excess of load, then 2-3rds of $823·16 = 548·77$, or say 548 inch-lbs. as being the effective power.

To find the diameter of the pump that such a wheel would work we must first know to what height the water is to be raised and the length of the stroke, from which we find the length of

the crank. Assuming these to be 80 ft. and 5 in. respectively, the diameter $= \sqrt{\dfrac{548}{\cdot 34 \times 80 \times 2\cdot 5}} =$ 8 and $\sqrt{8} = 2\cdot 8$ in. the pump's diameter.

As very few surface streams can be depended upon to give a constant and regular supply the size of the pump should not be calculated on the maximum but on the minimum, or when the stream yields the lowest quantity of water. In many cases the above size for the pump should be 2 in., and in others only 1½ in.

In the above calculations no allowance was made for friction of the water in the channel nor for the water which passed the wheel without doing duty and which cannot be avoided, no matter how well the wheel fits the race or enclosing walls.

We have before worked out the quantities of water that can be raised by pumps under varying conditions, but for the sake of the practice we will deal with the one above, but taking it as being 2 in. in diameter.

The pump having a 2 in. barrel with 5 in. stroke, worked at the rate of 11·76 strokes per minute. Then $2^2 \times \cdot 034 \times 5\text{-}12 \times 11\cdot 76 = \cdot 66$ gallons raised per minute, or 39·6 per hour, or 959·4 per day of 24 hours.

The water for turning the wheel being $8 \times 1 \times \cdot 5 \times 6\cdot 25 \times 60 = 1500$ gallons per minute, and the quantity raised ·66, the latter is equal to only 1-2272nd part of the whole quantity used.

The same wheel would work a double-action or a double-barrel pump, and thus raise twice the quantity in the same time, or if a treble-barrel pump were used three times the quantity would be raised with about the same expenditure of power.

As water wheels are usually fixed in valleys, or other positions lower than the houses, and frequently a considerable distance away, good size air vessels and small emptying cocks should be fixed on the delivery pipes as close to the pumps as possible. One form of a double-action pump and connection to the wheel is shown by Fig. 69, in which E is the pump, F the air

vessel, G the emptying cock, H the delivery pipe, I the suction pipe, J the plunger rod worked between guides, and K the wheel.

The power of an undershot is generally assumed to be about half that of an overshot wheel.

In most places wheels are used for pumping a portion of the water which drives them, but many streams are totally unfit for domestic use, or for drinking. In such cases the unsuitable

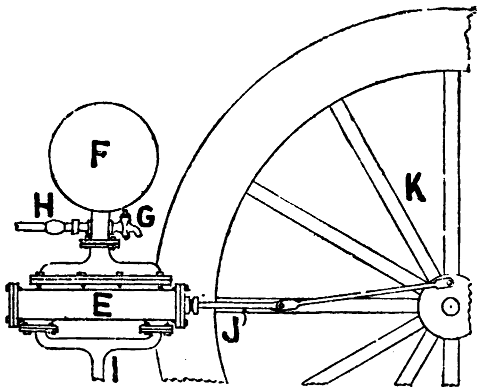

FIG. 69.

water can be utilised for turning a wheel and a pump or pumps, attached to the latter, can be made to raise water from a small spring, or well, which is pure and available.

Having dealt in an elementary manner with water wheels we can now pass on to other kinds of methods of raising water.

Chain Pumps.

A chain pump consists of a barrel which is parallel from the spout to the bottom, the latter being bell-mouthed, and an endless chain or short rods jointed together, on which discs of wood or iron are fixed at intervals. Over the top of the pump a wheel is fixed, as shown at

L, Fig. 70. This is turned by a crank handle, or winch, M. The discs fit the barrel loosely, or not so tight as to cause excessive friction which would make the pump difficult to work.

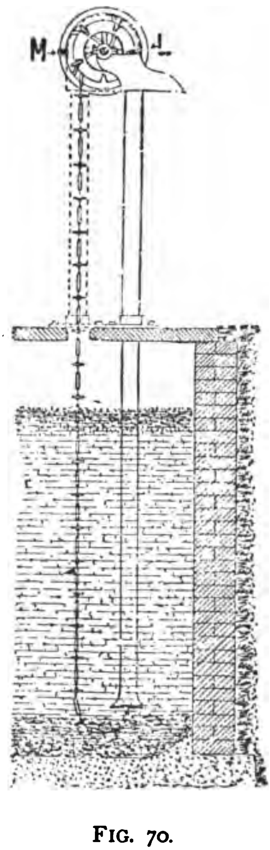

FIG. 70.

The bottom of the barrel is immersed in the liquid to be pumped so that it is filled for some distance On turning the handle the liquid is

carried up by the discs, when more runs in to be again taken up by the following discs. Some pumps have a hood over the top and the upper portion of the return chain enclosed, as shown by the dotted lines. These pumps are used principally for emptying cesspools or pumping water with which mud and sand is mixed.

They are fixed on planks, or tripod stands, with the spout high enough for discharging into mud, or nightsoil, carts. Although usually made of iron, and the barrel is round, contractors sometimes make them square in section of boards nailed together, and square wooden discs are used. The iron pumps, about 3 in. in diameter, are worked by hand, but large size contractor's pumps are sometimes turned by steam engines. These appliances are not suitable for raising water to great heights, and neither should they be worked at a very low speed as the amount of "slip" is considerable.

With regard to the power to work them, assume, as an example, that the spout is 10 ft. above the surface of the liquid in the cesspool or sump, and the pump has a 3 in. barrel. After turning the handle a few times until the barrel is filled there would be a column of liquid 3 in. in diameter and 10 ft. long. This liquid would probably be heavier than water, and if we assume that a cubic foot weighed 66 lbs., then the weight to be lifted would be :—

$$\frac{3^2 \times \cdot 7854 \times 66 \times 10}{144} = 32 \cdot 39 \text{ lbs.}$$

If the wheel which supported and turned the disc chain was 12 in. in diameter, the weight of the contents of the barrel would be suspended at a distance of 6 in. from the centre of the axle. And $32 \cdot 39 \times 6$ in. $= 194 \cdot 34$ inch-lbs. of resistance to be overcome. To this should be added an allowance for friction (which varies with the matter being lifted) and excess of power over load. If we assume that these combined just doubled the load, then the power to raise it should be not less than $196 \cdot 34 \times 2 = 388 \cdot 68$ inch-lbs. If the winch handle is 18 in. long, then

$388 \cdot 68 \div 18 = 21 \cdot 6$ nearly lbs. of power to be applied to the handle to work the pump with useful effect.

The quantity of liquid raised by these pumps is governed by the speed at which they are worked, and an ample allowance made for slip, or water escaping past the discs.

If the wheel is 1ft. in diameter, and turned at the rate of 25 times per minute, then $1 \times 3 \cdot 1416 \times 25 = 78 \cdot 54$ ft. which equals the length of a column of liquid 3 in. in diameter raised per minute.

And $3^2 \times \cdot 034 \times 78 \cdot 54 = 24$ gallons. From this should be deducted, say, $\frac{1}{6}$th for slip, and $24 \div 6 = 4$ and $24 - 4 = 20$ gallons, the actual quantity raised in the given time.

Although not usually practised the chain pump could be utilised as a power for moving machinery in much the same way as a water wheel. If the head of the pump shown by Fig. 70 was enlarged, the spout removed, and a stream of water made to run into the top, the weight on the discs would press them down and cause the wheel, L, to revolve and turn the crank of a pump or any other machinery to which it was geared.

Another machine in which the weight of water acts as a motive power is shown by Fig. 71, and is known as a "chain of buckets." The principle is somewhat similar to an overshot, or a breast, wheel, in that one side is loaded with water, the weight of which causes the buckets on that side to travel downwards. The bucket-chain is mounted on two drums, which have axles through their centres. The top one, N, is geared to any machinery it is desired to turn. Either drum can be used for this, but the upper one is more firmly gripped by the chain, than the lower one.

The equation for finding the power of this appliance is:—

$$I = \frac{R \times C}{W \times D}$$

Where R = the resistance.
C = length of crank.

W = weight of load in buckets.
D = radius of the wheel.

R and W, and C and D, should respectively be in the same terms.

To work out an example, assume that the loaded buckets contain 100 gallons, or 1000 lbs, the wheel is 3 ft. in diameter and the crank 6 in.

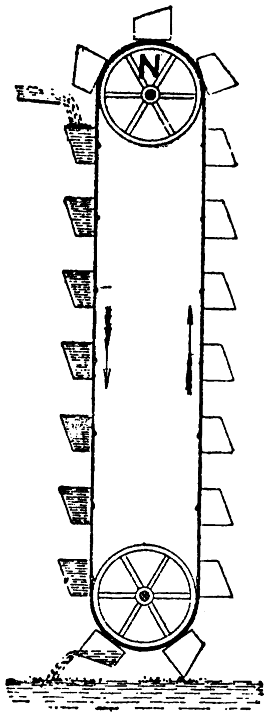

FIG. 71.

long; what weight, or resistance, on the crank would balance the loaded buckets?

$$\text{Then } R = \frac{1000 \text{ lbs.} \times 18 \text{ in.}}{6 \text{ in.}} = 3000 \text{ lbs.}$$

If the appliance had to do work and overcome the friction of the moving parts, instead of balancing the power, about ⅓rd of R should be deducted.

Then $3000 \div 3 = 1000$ and $3000 - 1000 = 2000$ lbs. representing R, or the load that could be lifted.

The action of the appliance could be reversed and made to lift the loaded buckets. Such appliances are used for dredging the beds of rivers and streams, or for hoisting grain and similar matters to higher levels or floors.

To find the power, using the last values, we have R (or in this case power) $= \dfrac{1000 \text{ lbs.} \times 18 \text{in.}}{6 \text{ in.}}$ $= 3000$ lbs. as before, but in this case ⅓rd should be added instead of being deducted. Then $3000 + \frac{1}{3}$rd of $3000 = 4000$ lbs. of power to be applied to the crank continuously to lift the loaded buckets.

If we assume that only 1000 lbs. of power are available but the loaded buckets and diameter of wheel remain the same, the crank should then be longer. To find the length:

$$C = \frac{1000 \text{ lbs.} \times 18 \text{ in.}}{1000 \text{ lbs.}} = 18 \text{ in.}$$

to just balance the load.

If we again assume that ⅓rd should be added, for reasons before given, then $18 + \frac{1}{3}$rd of $18 = 24$ in., the length the crank should be to raise the buckets under the given conditions.

The action of water wheels, too, is sometimes reversed and power applied, by means of a crank attached to the axle, to raise water by the buckets or floats. Many examples of these are found in the fens of Lincolnshire for draining the low-lying lands into the main drains which are at higher levels.

Although these do not come under the heading of plumbers' work a problem can be taken with the object of illustrating the principles.

For draining the land, sub-soil drains made of agricultural pipes, in many cases brushwood, or faggots of wood, are used instead of pipes, are laid to discharge into "dykes" or open

ditches, which run round the fields, and thence into main dykes which are dug with a fall towards a point near the high level main drain. Here buildings are constructed and powerful engines fixed for working the wheels or water elevators.

These are fixed between walls, as shown by Fig. 72. In the drawing, O is the water in the main drain and P that in the main dyke which

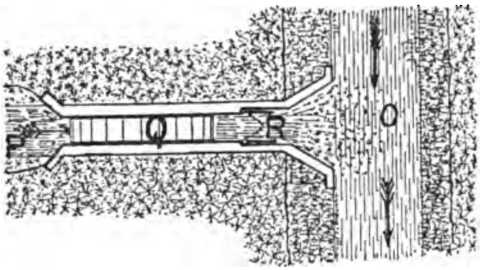

FIG. 72.

is at a lower level. Q is the wheel turned by shafting and gearing in connection with the steam engine. At R is a pair of doors or "gates," similar to lock gates, hung on hinges attached to the side walls so as to open outwards into the main drain. The gates are shown opened back into recesses. The dotted lines show them closed. When the wheel is being worked and the water lifted above that in the main drain, the pressure forces them open, but they immediately close by the back pressure when the wheel is stopped or ceases to raise the low level water.

The water lift, or difference of level between the high and low streams, is only a few feet, as shown by the sectional drawing, Fig. 73, in which the same reference letters are used as in Fig. 72.

If we assume a case of a wheel which has to raise water to a level 5 ft. higher than the dyke, at the rate of 100,000 gallons per hour, the floats being 1 ft. deep, the wheel's diameter 12 ft., and revolving five times per minute. To

find the width the wheel should be we proceed as follows:

Although 100,000 gallons have to be raised the wheel must be capable of raising that quantity plus that which escapes back owing to the difficulty of constructing the enclosing walls so that there shall be no waste. This quantity varies very much, but if we assume it to be 1-5th of the total we then have $100{,}000 + \frac{100{,}000}{5} = 120{,}000$ gallons in all, and the wheel should be capable of raising that quantity in the

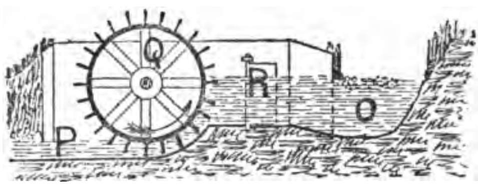

FIG. 73.

given time, although only 100,000 are actually lifted or delivered into the main drain.

We can now proceed to find what a wheel 1 ft. wide would do and from that find the actual width required.

For the contents of the buckets, or the quantity they hold, the simplest method will be to first find how much the wheel would hold when considered as a cylinder and deduct the centre portion.

Then $12^2 \times 4{\cdot}9 = 705{\cdot}6$ gallons.

And $10^2 \times 4{\cdot}9 = 490{\cdot}0$ gallons.

$\therefore\ 705{\cdot}6 - 490{\cdot}0 = 215{\cdot}6$ gallons.

The wheel has 24 floats and these being 1ft. $\times$ 1 ft. $\times$ $1\frac{1}{2}$ in. thick $= 3$ cubic feet of space occupied by them. Then $3 \times 6{\cdot}5 = 18{\cdot}75$ gallons to be deducted, and $215{\cdot}6 - 18{\cdot}75 = 196{\cdot}85$ gallons the net contents of the buckets. As 1-5th of the water escapes back, then

$$196{\cdot}85 + \frac{196{\cdot}85}{5} = 236{\cdot}22 \text{ gallons.}$$

The wheel revolves 5 times per minute and

$236{\cdot}22 \times 5 \times 60 = 70866$ gallons the gross quantity raised per hour with a wheel one foot wide.

Then $\frac{120000}{70866} = 1{\cdot}693$ or 1 ft. 8½ in. nearly, the width of the wheel to raise the given quantity per hour under the assumed conditions.

The h.p. of the engine necessary to work the above wheel, assuming one h.p. to be equal to 33,000 lbs. raised one foot high in one minute would be:

$$\frac{120{,}000 \text{ gallons} \times 10 \text{ lbs.} \times 5 \text{ ft.}}{33{,}000 \text{ ft. lbs. per minute} \times 60 \text{ minutes}} = 3 \text{ h.p.}$$

to which should be added ⅓rd for overcoming friction and excess of power over load = 4 h.p.

In practice, an engine double this, or say 8 h.p., would be necessary.

This has been only a very elementary problem, but it has served to further elucidate the power of water wheels and the resistance which has to be overcome when raising water to higher levels.

We have now considered the theory and practice of pumps and their working in all bearings of interest to plumbers, and I hope I have made myself clear in the details.

A great deal more could be said and written about them, but it is doubtful if any advantage would be gained by continuing this branch of our subject.

Appended are tables, for reference by practical men, of sizes of pumps and the theoretical quantity of water that they will raise. Also of pressures to be overcome when raising water to any height within the scope of ordinary practice.

Easy Rules for Finding Approximately the Quantity in Gallons Discharged by Pumps per Hour.

Single Pumps.

Worked at 20 strokes per minute.

$Diameter^2$	by	20·4	for	6 in.	stroke.
,,	,,	27·2	,,	8 in.	,,
,,	,,	30·6	,,	9 in.	,,
,,	,,	34·0	,,	10 in.	,,
,,	,,	40·8	,,	12 in.	,,

Worked at 25 strokes per minute.

$Diameter^2$	by	25·5	for	6 in.	stroke.
,,	,,	34·0	,,	8 in.	,,
,,	,,	38·25	,,	9 in.	,,
,,	,,	42·5	,,	10 in.	,,
,,	,,	51·0	,,	12 in.	,,

Double Pumps.

Worked at 20 strokes per minute.

$Diameter^2$	by	40·8	for	6 in.	stroke.
,,	,,	54·4	,,	8 in.	,,
,,	,,	61·2	,,	9 in.	,,
,,	,,	68·0	,,	10 in.	,,
,,	,,	81·6	,,	12 in.	,,

Worked at 25 strokes per minute.

$Diameter^2$	by	51·0	for	6 in.	stroke.
,,	,,	68·0	,,	8 in.	,,
,,	,,	76·5	,,	9 in.	,,
,,	,,	85·0	,,	10 in.	,,
,,	,,	102·0	,,	12 in.	,,

Treble Pumps.

Worked at 20 strokes per minute.

$Diameter^2$	by	61·2	for	6 in.	stroke.
,,	,,	81·6	,,	8 in.	,,
,,	,,	91·8	,,	9 in.	,,
,,	,,	102·0	,,	10 in.	,,
,,	,,	122·4	,,	12 in.	,,

Worked at 25 strokes per minute.

$Diameter^2$	by	76·5	for	6 in.	,,
,,	,,	102·0	,,	8 in.	,,
,,	,,	114·75	,,	9 in.	,,
,,	,,	127·5	,,	10 in.	,,
,,	,,	153·0	,,	12 in.	,,

The following tables are based on the foregoing rules.

TABLE I.

SINGLE PUMPS.—Worked at 20 strokes per minute.

Diameter in inches.	Gallons raised per Hour.				
	6in. stroke.	8in. stroke.	9in. stroke.	10in. stroke.	12in. stroke.
2	81	102	122	136	163
2½	127	170	191	212	255
3	183	244	275	306	367
3½	250	333	374	416	499
4	326	435	489	544	652
4½	413	550	619	688	826
5	510	680	765	850	1020
6	734	979	1101	1224	1468
7	999	1332	1499	1666	1999
8	1305	1740	1958	2176	2611
9	1652	2203	2478	2754	3304
10	2040	2720	3060	3400	4080
12	2937	3916	4406	4896	5875

TABLE II.

SINGLE PUMPS.—Worked at 25 strokes per minute.

Diameter in inches.	Gallons raised per Hour.				
	6in. stroke.	8in. stroke	9in. stroke.	10in. stroke.	12in. stroke.
2	102	136	153	170	204
2½	159	212	239	265	318
3	229	306	344	382	459
3½	312	416	468	520	624
4	408	544	612	680	816
4½	516	688	774	860	1032
5	637	850	956	1062	1275
6	918	1224	1377	1530	1836
7	1249	1666	1874	2082	2499
8	1632	2176	2448	2720	3264
9	2065	2754	3098	3442	4131
10	2550	3400	3825	4250	5100
12	3672	4896	5508	6120	7344

NOTE.—These tables also give the quantity raised by a double-barrel pump with wheel and pinion motion geared 2 to 1, or a treble-barrel pump geared 3 to 1, when the crank shaft revolves 20 and 25 times per minute.

TABLE III.

Double Pumps.

Worked at 20 strokes per minute.

Diameter in inches.	Gallons raised per Hour.				
	6in. stroke.	8in. stroke.	9in. stroke.	10in. stroke.	12in. stroke.
2	163	216	244	272	326
2½	255	340	382	424	510
3	367	488	550	612	734
3½	499	666	748	832	998
4	652	870	978	1088	1304
4½	826	1100	1238	1376	1652
5	1020	1360	1530	1700	2040
6	1468	1958	2202	2448	2936
7	1999	2664	2998	3332	3998
8	2611	3480	3916	4352	5222
9	3304	4406	4956	5508	6608
10	4080	5440	6120	6800	8160
12	5875	7832	8812	9792	11750

TABLE IV.

Double Pumps.

Worked at 25 strokes per minute.

Diameter in inches.	Gallons raised per Hour.				
	6in. stroke.	8in. stroke.	9in. stroke.	10in. stroke.	12in. stroke.
2	204	272	306	340	408
2½	318	424	478	530	637
3	459	612	688	764	918
3½	624	832	936	1040	1258
4	816	1088	1224	1360	1632
4½	1032	1376	1548	1720	2065
5	1275	1710	1912	2124	2550
6	1836	2448	2754	3060	3672
7	2499	3332	3748	4165	4998
8	3264	4352	4896	5440	6528
9	4131	5508	6196	6884	8262
10	5100	6800	7650	8500	10200
12	7344	9792	11016	12240	14688

TABLE V.

Treble Pumps.

Worked at 20 strokes per minute.

Diameter in inches.	Gallons raised per Hour.				
	6in. stroke.	8in. stroke.	9in. stroke.	10in. stroke.	12in. stroke.
2	244	326	367	408	489
2½	382	510	573	637	765
3	540	734	826	918	1101
3½	749	999	1124	1249	1499
4	979	1305	1468	1632	1958
4½	1239	1652	1858	2065	2478
5	1530	2040	2295	2550	3060
6	2203	2937	3244	3672	4406
7	2998	3998	4498	4998	5996
8	3916	5222	5875	6528	7833
9	4957	6609	7435	8262	9914
10	6120	8160	9180	10200	12240
12	8812	11750	13219	14688	17625

TABLE VI.

Treble Pumps.

Worked at 25 strokes per minute.

Diameter in inches.	Gallons raised per Hour.				
	6in. stroke.	8in. stroke.	9in. stroke.	10in. stroke.	12in. stroke.
2	306	408	459	510	612
2½	477	636	717	796	954
3	688	918	1032	1147	1377
3½	937	1249	1405	1561	1874
4	1224	1632	1836	2040	2448
4½	1549	2065	2323	2581	3098
5	1912	2550	2868	3187	3825
6	2754	3672	4131	4590	5508
7	3748	4998	5622	6247	7497
8	4896	6528	7344	8160	9792
9	6196	8262	9294	10327	12393
10	7650	10200	11475	12750	15300
12	11016	14688	16524	18360	22032

TABLE VII.

Pressure in lbs. to be overcome in raising water by pumping from 10 to 200 ft. perpendicular, measured from surface of water in well or reservoir to delivery tank.

Rule.—Diameter in inches squared × ·34 for each foot vertical height.

Height in feet.	Diameters of Barrels.													Height in feet.
	2	2½	3	3½	4	4½	5	6	7	8	9	10	12	
10	13·6	21·2	30·6	41·6	54·4	68·8	85·0	122·4	166·6	217·6	275·4	340·0	489·6	10
20	27·2	42·5	61·2	83·3	108·8	137·7	170·0	244·8	333·2	435·2	550·8	680·0	979·2	20
30	40·8	63·7	91·8	124·9	163·2	206·5	255·0	367·2	499·8	652·8	826·2	1020·0	1468·8	30
40	54·4	85·0	122·4	166·6	217·2	275·4	340·0	489·6	666·4	870·4	1101·6	1360·0	1958·4	40
50	68·0	106·2	153·0	208·2	272·0	344·2	425·0	612·0	833·0	1088·0	1377·0	1700·0	2448·0	50
60	81·6	127·5	183·6	249·9	326·4	413·1	510·0	734·4	999·6	1305·6	1652·4	2040·0	2937·6	60
70	95·2	148·7	214·2	291·5	380·8	481·9	595·0	856·8	1166·2	1523·2	1927·8	2380·0	3427·2	70
80	108·8	170·0	244·8	333·2	435·2	550·8	680·0	979·2	1332·8	1740·8	2203·2	2720·0	3916·8	80
90	122·4	191·2	275·4	374·8	489·6	619·6	765·0	1101·6	1499·4	1858·4	2478·6	3060·0	4406·4	90
100	136·0	212·5	306·0	416·5	544·0	688·5	850·0	1224·0	1666·0	2176·0	2754·0	3400·0	4896·0	100
110	149 6	233·7	336·6	458·1	598·4	757·3	935·0	1346·4	1832·6	2393·6	3029·4	3740·0	5385·6	110
120	163·2	255·0	367·2	499·8	652·8	826·2	1020·0	1468·8	1999·2	2611·2	3304·8	4080·0	5875·2	120
130	176·8	276·2	397·8	541·4	707·2	895·1	1105·0	1591·2	2165·8	2828·8	3580·2	4420·0	6364·8	130
140	190·4	297·5	428·4	583·1	761·6	963·9	1190·0	1713·6	2332·4	3046·4	3855·6	4760·0	6854·4	140
150	204·0	318·7	459·0	624·7	816·0	1032·8	1275·0	1836·0	2499·0	3264 0	4131·0	5100·0	7344·0	150
160	217·6	340·0	489·6	666·4	870·4	1101·6	1360·0	1958·4	2665·6	3481·6	4406·4	5440·0	7833·6	160
170	231·2	361·2	520·2	708·0	924·8	1170·5	1445·0	2080·8	2832·2	3699·2	4681·8	5780·0	8323·2	170
180	244·8	382·5	550·8	749·7	979·2	1239·3	1530·0	2203·2	2998·8	3916·8	4957·2	6120·0	8812·8	180
190	258·4	403·7	581·4	791·3	1033·6	1308·2	1615·0	2325·6	3165·4	4134·4	5232·6	6460·0	9302·4	190
200	272·0	425·0	612·0	833·0	1088·0	1377·0	1700·0	2448·0	3332·0	4352·0	5508·0	6800·0	9792·0	200

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